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**SCIENCE, TECHNOLOGY AND AGENCY IN THE
DEVELOPMENT OF DROUGHTPRONE AREAS:**

A COGNITIVE HISTORY OF DROUGHT AND SCARCITY

Linden Faith Vincent Msc

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**Development Policy and Practice
Technology Faculty
Open University**

Author No: M7204730
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Science, technology and agency in the development of droughtprone areas: a cognitive history of drought and scarcity.

Abstract

Drought and scarcity are two frameworks in common use to study the relationships between natural phenomena creating lack of water (drought) and the lack of access to water for human security and economic development (scarcity). This thesis studies how these frameworks have shaped public action in droughtprone and scarcity regions over time, in the agencies created for water development, and their cognitive and technical norms used in analysis of drought and scarcity and design of development programmes. These public agencies have relied on science and technology both to generate new understanding of drought mechanisms and social and environmental dynamics shaping scarcity, and also mobilise water sources to reduce vulnerabilities in droughtprone regions. It explores two hypotheses: that scientific, technological and political elites build their power – or struggle to remain prominent actors – through the cognitive and technical norms that they build; and that a cognitive framework linking drought and scarcity can transform options to assess, allocate and use water resources in droughtprone areas. The thesis presents case studies from three droughtprone regions, India, Yemen and Zimbabwe. These regions have different patterns of drought risk and intensity, which manifest themselves in different dependencies and risks on different water sources - soil moisture, groundwater and surface water - to support agricultural production. They are also very different types of state in terms of their commitment to public action for development. The countries show differing dependencies on techno-scientific networks, techno-economic networks and district and community level management in shaping livelihood security in the face of drought, and have had different performances in mitigating drought impacts and creating equitable institutions to mediate scarce water resources. Future public action will be better informed by the emergence of critical science with a stronger commitment to shared knowledge and participatory debate.

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ACRONYMS

AMD-IMD	Agricultural Meteorology Division, India Meteorological Office
AP	Andhra Pradesh
APIL	Agro Pumpsets and Implements Limited
APRLP	Andhra Pradesh Rural Livelihood Programme
APSIDC	Andhra Pradesh State Irrigation Development Corporation
APSCRIC	Andhra Pradesh State Cooperative Rural Irrigation Corporation
APCCADB	Andhra Pradesh Cooperative Central Agricultural Development Bank
APWELL	Andhra Pradesh Ground Water Bore Well Irrigation Scheme project
BDO	Block Development Officer
BSAC	British South Africa Company
BUA	Borewell User Association
CAPART	Council for the Advancement of People's Actions and Rural Technologies
CI Wells	Community irrigation wells
CGIAR	Consultative Group for International Agricultural Research
CGWB	Central Groundwater Board
CLCCD	Confederation of Local Councils for Cooperative Development
DFID	Department for International Development
DPA-AP	Droughtprone Area, Andhra Pradesh
DPAP	Drought Prone Area Programme
DPAM	Droughtprone Area, Maharashtra
DRDA	District Rural Development Agency
FYP	Five Year Plan
GOI	Government of India
GSO	Geological Survey of India
gph	gallons per hour
hp	Horsepower
HYV	High Yielding Varieties
ICAR	Indian Council for Agricultural Research
ICRISAT	International Centre for Research in the Semi-Arid Tropics
IMD	India Meteorological Department
IRDP	Integrated Rural Development Programme
ISI	International Standards Institute
KAWAD	Karnataka Watershed Development Programme
LDA	Local Development Associations
LCCD	Local Council for Cooperative Development
MACS	Mutually Aided Cooperative Societies
l/s	litres per second
MWRR	Ministry of Water and Rural Resources
mm	millimetres
NABARD	National Bank for Agriculture and Rural Development
OMAI	Optimal Moisture Availability Index
P:PET	Precipitation: Potential Evapotranspiration
PHC	Primary Health Care
PHM	Participatory hydrological monitoring
PR	Panchayat Raj
SCSTS	Scheduled Caste and Scheduled Tribe Societies
SGSY	Swarnajayanthi Gram Swarozgari Yojana
SOPPECOM	Society for People's Participation in Ecosystem Management
YR	Yemen Arab Republic
ZINWA	Zimbabwe National Water Authority

PREFACE AND ACKNOWLEDGEMENTS

This PhD thesis enters into two critical areas of debate and analysis: the study of drought and scarcity conditions, and the relation of science, technology and agency in the public decision making and action for regions experiencing these water management conditions. The integrated understanding of both is, I think, critical for an increasing number of countries as pressure on water supplies increase.

Doing a PhD in mid-late career, around a review of past work and publications and contemporary debates, is not only a challenge in a work context, but it is also especially a personal one. It required both a critical recall but also a renewed confrontation with my older ideas, norms and analytical approaches, and reflection about my own change. In the end, however, this has proved an inspiration and a new source of enthusiasm for future work and better understanding both in the field of drought and water scarcity, and for the scope of post-normal science to contribute to better public action in relating water management and rural development

The opportunity to do this PhD with the Open University has been an important one. I particularly thank my supervisors, Professor David Wield of the Technology Faculty and International Development Centre at the Open University, and Dr. Ben Crow of the University of California, Santa Cruz, for their enthusiasm, critical insights and personal support. Their understanding of both the field of work, but also the struggles for fully employed students to craft a PhD has been an important contribution both to the arguments and lines of the thesis, and its completion. The well-designed structures of the Open University also gave much help in the combination of work and PhD writing. These experiences have been a learning process for my own supervision work.

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Financial support for different research studies came from the then Ministry of Overseas Development and the Economic and Social Research Council in the UK, and both the UK and Dutch Government supported other missions I was involved with for water related studies in India. Oxfam gave me a unique opportunity to work in the Yemen Arab Republic.

It is to my family and friends, home and abroad, who have provided a personal support team through the many difficulties and uncertainties of both the research and the odyssey of writing a PhD, and who help ensure I crossed the final submission line, that I give this final, heartfelt thank you.

CHAPTER 1 INTRODUCTION

While drought is a meteorological phenomenon, scarcity represents its impact on the socioeconomic life of that region. Scarcity may include drought but drought need not necessarily result in scarcity conditions...Quite often, droughtprone areas are wrongly identified with economically backward regions. Government of Maharashtra, 1973, Vol 1, p.37

1.1.1 PROBLEM STATEMENT AND OBJECTIVES

1.1. The scope of this thesis

This thesis builds a cognitive history of drought and scarcity through a study of science, technology and agency used to analyse drought and transform water availability in droughtprone areas. It looks at why and how society has come to see drought and water scarcity as risks needing public action; and how, why, and to what extent, science and technology have primacy in defining public action in the droughtprone areas. It examines what has changed in understanding of development in drought- and scarcity-affected communities, and why these areas still generate direct action and contestation despite growing understanding of natural mechanisms and social relations mediating water use.

As the opening quote shows, there have been two cognitive frameworks shaping knowledge for public action in droughtprone areas: drought and its associated risks, and scarcity and its mitigation. That of drought has looked at the dynamics of the water cycle as shaped by dry periods, focusing onto the different cycle elements – soil moisture, surface water and groundwater - as progressively mobilised for use in droughtprone areas, and the materialisation of manmade drought as water resources become over-developed. That of scarcity has moved from a focus on scarcity of

economic opportunity and precariousness of food supply shaped by limited and uncertain water supplies, to a framework of water scarcity involving problems of water access. This scarcity is shaped by social relations and water management that limit action to build new institutions to mediate this scarcity, as well as physical and economic forces. This thesis studies the development of these frameworks, and the shifts between them, in the evolution of development policies and programmes in droughtprone areas.

A first hypothesis of this thesis is that scientific, technological and political elites build profiles, or struggle to remain prominent actors in release of water technology, through their cognitive and technical norms, and limit and contest new knowledge networks and new science. Also, how these cognitive networks and possible transformations evolve is hugely shaped by the developmental nature of the states they are part of, and state-locality relations within them. Within public agencies, the development and protection of scientific and technical norms is often justified in the name of good science and technology to advise or help the public good. However, pursuit of such norms for their own sake, and in the interests of self-preservation can often work against the real power of such evolved norms to have public acceptability and legitimacy, and be a real power to shape sustainable development. Dowding (1996) distinguished 'power to' from 'power over', where the former is about outcome power, to bring about or help bring changes in outcomes. The latter is about social power, or the ability of one actor to change the actions of another. Scientists and engineers have often assumed that their findings and norms create knowledge and rational decision-making for positive change in public welfare, and thus also reinforce their status in public decision-making. This study proposes that persistence with embedded norms for protection of agency profiles without their regular review for relevance and acceptance

in new problem contexts, can lead to losses of both sources of power in the public domain. Funtowicz and Ravetz (1999, 1990) traced the evolution of ‘post-normal science’ as an approach capable to investigate complex environmental problems with high degrees of uncertainty within them. Such science focuses on the quality of data and norms rather than just experimental design of hypothesis testing, and participation in decision-making along with others espousing different knowledge – in contrast to a narrow focus on incremental and experimentally-derived physical knowledge and belief in the superiority and primacy of quantitative analysis. Much of this thesis is about the failure of such post-normal science to find a place inside most specialty agencies - as well as the struggle of some scientists and professionals to preserve a serious debate about known knowledge of the biophysical world and technology in new struggles in water management.

A second hypothesis is that these two cognitive frameworks have emerged and retreated over time in relation to the politics of their agencies rather than cognitive shifts, becoming discourses that compete rather than inform each other. However, better future integration can transform options to discuss water shortage problems, reshape knowledge systems and act for change. In such a new framework there are still important and interesting roles for science – but it demands recognition of the technological and social contexts shaping the demand for knowledge, and that wider public cognition can and should shape the scope of science and technology in societal futures. This study uses a conceptual framework built around cognition (see Chapter 2), and applies this to a study of science, technology and agency in three different countries – India, Yemen and Zimbabwe. It aims to show the struggles, inertia and transformations in key scientific fields of endeavour related to drought study, and in techno-scientific, bureaucratic and local agencies shaping water use.

1.1.2 The problem context

The struggle of farmers against poverty and insecurity to live in droughtprone areas has been of prominent concern for their governing states and their publics. Climates with significant dry periods and irregular rainfall - drought - affect some 67% of the African continent, 65% of Asia and 20.5 million hectares (2%) of Latin America – shaping the lives, livelihoods and social relations of people living there, and the public action taken to reduce the social stresses that drought brings. Traditionally public action in these areas was concerned to combat famine and food insecurity triggered by failure of production and exchange mechanisms consequent to drought. However, development policies for droughtprone areas also sought to release their economic potential if critical scarcities (including water) could be overcome. These older concerns have been made more urgent by the contestations emerging as ‘man-made’ drought and scarcity conditions create competition for water through the combination of over-development and unequal access, brought about by the over-allocation and use of rivers and aquifers. Thus there is a new urgency to discuss more appropriate hydrology planning, technology choices and design approaches to water systems and their operation in droughtprone areas.

There is now more than a century of public action recorded in the droughtprone regions (Government of Maharashtra, 1973), based heavily on new science and technology promoted to meet their needs. Much research has shown that these public interventions have massively reduced the risks of famine, and brought water supplies to more farmers (Sinha et al, 1987). Yet other research has shown that significant inequalities and vulnerabilities remain in livelihood security (Agarwal, 1991). Farmers have lost as well as gained water access under new irrigation development (Dubash,

2002; Knecht and Vincent, 2001), and the poorest must often still lobby, strategise and protest to preserve or gain access to food and water in a drought (Omvedt and Patankar, 1991). Struggles around new water development programmes and laws show that the public deliberations underpinned by science and elite techno-scientific agencies are often seen to lack accountability, legitimacy or even reliability (Lemos, 2003; Waller, 1994). Meanwhile, local people have diverse experiences and pluralistic views on the nature and causes of water scarcity that few public agencies and scientists interact with (Mehta, 1998). Clearly the knowledge generated on drought events, and the stresses on people struggling for water access in droughtprone areas, is still insufficient, inappropriate or contested in planning action.

How and why such struggles continue, and implementation and intervention fall short of expectations and have unforeseen consequences despite reshaping of policies and programmes with conscious deployment of science and technology, is the focus of this thesis. It also hopes to show that there have been changes in knowledge and action for living with drought, through changing cognition. While many problems remain, by understanding these inconsistencies and struggles we can learn more for future action.

Despite the growing concern over competition for water and vulnerability of societies to drought, there are still few comparative studies on cognition behind public action in droughtprone areas. Douglas (1985) emphasized the importance of recognising how and why societies highlight the risks they do, and choose to face them in particular ways. Allan (1993) asserts that, when we explore the social realities creating scarcity conditions, we can better negotiate their stresses and avoid war and violent conflict. Many authors recognise that policy development and implementation is greatly influenced by the scientific and technical information accepted (Sarewitz and Peilke, 1999, Thomas et al, 1998), and there are a few excellent studies showing the

interplay of water development, technology choices, elites and water politics (Waller, 1994; Mollinga, 1998). However, studies that relate such political dynamics back into the heartland of scientific and engineering calculations and document their implications for water development and access, are rare even for one state or water sector (Lemos 2003; van Halsema, 2002). This thesis attempts such a study in a range of states for a range of water sources over time. It aims to show changing cognition in policy formulation¹ and action by states and their public agencies, of the social processes in which science and technology are embedded, and the roles these processes continue to play in determining water resource dynamics and resource access in droughtprone areas. It also presents my own changing cognition in development-related research, with a hope to inform the possibilities for action by practitioners, communities and governments in the future.

1.1.3 What is a droughtprone area?

To many, a droughtprone area is a socionatural region with climates and societies affected by dry periods. A gradation of annual average rainfall criteria has been used as an indicator of worsening climatic challenges for agriculture. The first is an annual average rainfall of 800-1000 mm, where crop production is fairly assured but drought can bring crop failure of one year in 7-10 years. The second is an average annual rainfall of 500-800 mm, where crop options are more constrained and there are also higher risks of low rainfall and crop failure in one year in four or five. The problematic nature of risks in cropping has focused most international attention on this regime. The

¹Leftwich (2000) described policy formation as courses of action with means of implementation and outcomes.

last is the annual average rainfall of 300-500 mm, where crop failure can come one year in three or less, and agriculture is geared to much lower expectations of rainfall. (Cocheme and Franquin, 1967; ICRISAT, 1978(iii); Wallen, 1967) As climates become drier, so runoff is less, and dependencies on groundwater and special storage technologies become greater. The social mechanisms that regulate risks and control access to water vary not only with the drought risk context but also the society living under it. These social actions shape the nature of the 'scarcity' that materialises in relation to access to water. The actions of science, technology and agency in shaping the development of societies in these three droughtprone regimes with very different dependencies on different water sources - Zimbabwe, India and Yemen respectively – are the focus of this thesis.

Looking from the perspective of water supply, drought brings risks of food and water insecurity, and even famine – risks and hazards to be mitigated through our capacities to mobilise water and production for food, domestic needs and economic opportunity (Subramaniam, 1975). Looking from the economy of the region and life of its people, drought is significant in its creation of vulnerable livelihoods for producers, risky production for farm output and regional economic transformation, and thus impoverishment of people and stagnation of regions (Jodha, 1991). These are production conditions that science and technology have aimed to change through better water security and transformed farming systems, to find niche opportunities and new livelihoods, ensure basic needs, and build regenerative capacity and resilience to environmental fluctuations and shocks (Datye et al, 2000).

However, looking from social relations that will evolve to control and mediate these actions around water and development - especially as mediated by power, knowledge and labour processes – droughtprone areas are not only natural habitats but also social

arenas. These involve actions around water control technologies and resource capture and exclusion, exploitative agrarian relations, coercive and authoritarian control, and control of personal and social destinies. Development arenas can also be studied as cognitive spaces, by examining political, social and technical performances around particular technological problems (Jorgensen and Sorensen, 1999). Such a study then brings a focus on key actors and locations of action, artefacts with associated science-technology relations and techno-economic networks, plural knowledge and visions, and transformations that stabilise or destabilise social and ecological relations around artefacts (Jorgensen and Sorensen, 1999). Studying droughtprone areas as cognitive spaces and not only ecological habitats, allows the bringing together of what otherwise might seem like a 'patchwork of science and technology stories' to see conflicting interests and contentions - and sometimes possibilities for concerted action if conscious social learning and collective planning takes place. Public agencies are actors in these spaces not only through the science and technology they deploy, but also how they allow for epistemological pluralism and social contestation. Arenas can be changed as new actors, actor-networks and ideas enter them to re-shape technology use and resource access, and the analysis of their risks and design challenges as well as potential benefits. It is this history that this thesis studies.

1.1.4 Objectives and target audiences

It is the cognition of the professional that shapes whether they define their work (as individual and group) in narrow performance terms around their own technoscientific concerns, or they truly recognise the complexity of the cognitive space and development arena they are part of. With this wider understanding, they can recognise

and critically evaluate their choices in the scientific routines and artefacts deployed, and strategic social networking. Thus the first objective of this thesis is to show what cognition has directed water planning and water-related development within droughtprone and scarcity regions, its weaknesses and biases, and how it has begun to change. Among some professionals and researchers, there is now an increased interest and commitment to greater inter-disciplinarity, recognition of different knowledge systems, and acknowledgement of the political action often necessary to shape redesign and implementation processes in development intervention and resource planning. The target groups here are hydrologists, engineers and development practitioners working in natural resource management.

The second objective is more ambitious and difficult - to raise awareness about both how to plan participation and encourage negotiation, but also how to recognise the power struggles such actions are embedded within. As Dreze and Sen (1989 p.259) argue ...”Public action is not ...just a question of public delivery and state initiative. It is also....a matter of participation by the public in the process of social change”. It is not just whether and how we allow this participation that is very important. Rather it is conscientisation in how to work with local people’s expression of their wants, their experience of scarcity and the risks in their social action – which can come in violent forms as well as policy dialogues. In this respect, cognitive understanding can merge with and complement a wider political economy perspective to strategise and debate social action, beyond just recognition of plurality of knowledge systems and discourses. Policy-makers and planners, water activists, group action facilitators and ‘front-line’ water workers and engineers are the target groups here.

A third objective is to promote cognition that will enable resource use and social processes, and their mediation by technology, to be understood together with better

integrated understanding of mediations for drought and scarcity. Scientists, engineers, policy makers and governance representatives are the target audiences here.

Such different target groups means that this thesis needs a 'users' guide, as some sections are quantitatively scientific and technical in nature, while others are more descriptive of policy, governance, regulation and participation dynamics. These are given in each chapter. Users themselves remain beyond the target of this study, but I hope they can ultimately benefit from more aware public agents to work with.

To these ends the thesis uses case studies that both interpret the science and technology employed by different states and agencies – and describe my own cognitive frameworks and learning. The thesis uses case studies of 'public water action' from Maharashtra and Andhra Pradesh States in India, Zimbabwe and Yemen with reference particular eras of time. The focus of this study is on small water systems in rural areas. In the countries studied, these dispersed systems nevertheless help supply major quantities of water resources critical to smallholders, which are also seen as increasingly 'non-governable' by public water agencies. They thus discuss a social context of technological water control relevant to many states and local groups at this time. The thesis uses a conceptual framework focused on the interplay of nature-technology-society in the development of droughtprone areas, studied in relation to different water resources, technologies and states, outlined in Chapter 2.

1.2 WHAT IS A 'COGNITIVE HISTORY' AND WHY IS IT RELEVANT?

1.2.1 Some definitions of cognition

When Blackmore and Ison (1998) mentioned 'cognitive history' they were talking of change in individual knowledge and experience. However, cognition exists in collectivities, such as states, techno-scientific agencies, and communities. It is shown in the knowledge they promote and use for action, whether for the power of elites or a more common good. Synthesizing various dictionary and encyclopaedia definitions², I define cognition as.... the process involved in knowing or act of knowing, especially as it affects learning and behaviour, in which experience and intuition as well as learned information plays a role. For this study, I see it as involving all processes of consciousness by which understanding is built up. I see related within it not only the field of cognisance (judicially allowed knowledge, calculation, patterning, mathematical compression, and judgement) but also conscientization (Freire 1972)³, which shapes how people understand their relations with each other and the world, and linkages between them. Conscientisation is also critical in how knowledge is understood as power, and how concepts of process and strategy get built into ideas for concerted action. Nightingale (1998) stresses that knowledge is embedded in social practices and networks, such that collective innovation is about shared understandings, beyond an aggregate of individuals.

Cognition has held a central place in research and conceptual development in science and technology studies, particularly in relation to organisational learning and innovation. However, in the application of cognitive approaches (that study knowledge

² Encyclopedia Britannica cdrom, Chambers Giant Paperback dictionary

and learning) to development agency, part of this field can also be studied through discourse analysis. Foucault (1969) includes as discourse the concepts and codes by which societies operate, which are also seen to evolve historically and socially rather than as pure evolutionary knowledge. Discourse analysis can show which concepts become used, and how and why they are used, in the political functions of controlling people and developing power, rather than in developing understanding. Thus to some, discourse analysis can be a frame of study that subsumes cognition – indeed cognition can even become framed as a discourse, giving an acceptable language to a dialogue with organisations on how they must transform. However, in this study, I am concerned about self-generated change in understanding, which can analyse as well as act against dominant controls. Thus I take recognition of discourse as part of cognition – indeed a critical one for agencies, groups and individual professionals concerned for transformation in knowledge and action. The understanding of how discourses become used in the contested access to natural resources, as well as how they shape accredited knowledge and agency, is an essential part of conscientization, and recognition of process as critical to strategising change. A wider perspective of cognition helps critical assessment of data use and quality behind discourses, and helps more critical reflection on one's own findings and arguments. If we are to change discourses that have generated problematic transformation or exclusion, then to agree new ones, we need a cognitive framework that also includes political and scientific consciousness.

³ The term conscientisation refers to learning to perceive social, political and economic contradictions, and to take action against oppressive elements of reality (Freire 1972 p.15).

1.2.2 Why ‘a history’?

Carr (1964) points out that when we answer what is history, our answer reflects our own position in time and is related to the view we have of the society we live in. History is not only the facts of the past, but analysis of the ideas, relations and ideologies that are understood in the particular fields of the past focused upon – and present in the writer themselves. The onslaught of science and technology on the environment has led some to say we are in an era after nature and at the end of history, left with only political ecology (Escobar, 1999). However, the answer is that we live in society as well as nature. Our facts need to keep us constantly aware of what structures our relations between them. Carr shows that the dual function of history is both to help understand the society of the past, and to increase mastery over the society of the present – and the spaces people exist in. We learn from it in ways that enable us to explore not only why but whither. It allows us, and encourages us to declare our faith in the future.

A cognitive history then, not only includes some study of knowledge related to public action. It is also the study of how these relate to the materialisation of change in society and resource dynamics: how one superstructure of knowledge agency interacts with another infrastructure of power agency (Cohen, 1976), often through the technology promoted. It also includes awareness of the way the student interacts with ‘their facts’ and thinks about the present and future. This research thus focuses on two particular levels of development policy investigation (Potter and Subramaniam, 1998): the concepts underpinning development policy and their change, and the ‘capacities for change’ in institutions involved in local management and intervention. In chapters 5 and 6, this thesis also addresses the local level – the experiences of change by local

water users - but this is done to illustrate weaknesses arising from these policy and agency levels, rather than document local agrarian change processes in depth.

1.3 RESEARCH QUESTIONS

How have science and technology shaped public agencies and action in development of water in droughtprone areas, and public cognition on water availability and access?

Subquestions:

1. What changes are present in definitions of drought, droughtproneness and scarcity over time, and how and why are these different in agricultural, groundwater and surface water contexts?
2. How have these framed the cognitive practices of agencies and institutionalised actors active in droughtprone areas, and to what extent have these changed the cognitive and technical norms of their working practices?
3. What diversity is visible in public agency over water resources in droughtprone areas, in different nation states, and why and how have these changed over time?
4. How has cognition about technologies in use to mediate water supply in droughtprone areas shaped the science used in analysis and allocation of water resources and transformation of physical water systems?

However, as explained, I want to show my own personal change while doing this study.

I therefore write two shadow questions, which structured my research at different times. I will differentiate what was my starting condition – which I think was an

objective/instrumentalist approach to research (Blackmore and Ison 1999), and a later a cognitive/political economy approach (Nightingale, 1998; Mollinga, 1998).

Shadow 'objective/instrumentalist' question: How can the study of drought risk and water availability in drought-prone areas contribute to water development interventions to transform droughtprone areas?

Such a question, which assumes water is the essential factor shaping the conditions of society, not only makes researchers study too narrowly so they miss realities and real trends. It also brings great dangers through the way they miss political realities and misread the public mood for action – leading to conflict, or problems for assistants who might be accused of wrongdoing or penalised for their work relationships with research or intervention initiatives (as the Andhra Pradesh and Yemen cases discuss). Chapters 3 and 4 are dedicated to showing the problems of cognition generated by such a question.

Shadow 'cognitive/political economy' question: How have public agencies in droughtprone areas used science and technology in interventions to assess risks and transform water availability in droughtprone areas, and shaped social processes and outcomes in water use, resource capture and evolution of water use systems?

The second shadow question informed my later work. Such questions can yield rich understanding of designs, power struggles and intrigues around water. If research resists too glib an explanation and naïve a faith in a technological future, it can also assist new interventions around technology. This question informs research in Chapters 5-7 for India, Yemen and Zimbabwe.

1.4 SELECTION OF COUNTRIES FOR COMPARATIVE STUDY

The selection of countries for this study (India, Yemen and Zimbabwe) was made with reference to both distinctive differences in states and drought contexts, but also to the nature of the development questions my research or project work was involved with.

These included:

- Existence of a significant area of territory with low and uncertain rainfall which also shaped seasonal fluctuations and availability of surface runoff and groundwater, where there had also been public action to develop technologies for agricultural and domestic water supply and regulate access to water;
- The relative importance of different elements of the water cycle in their economic and social development, to enable in-depth investigation of the scientific and technical norms to assess drought and scarcity conditions for rainfall, groundwater (wells and springs) and surface water sources;
- To enable explicit recognition of different institutions in existence for planning, implementing, managing and advising on water development for rural transformation in different countries, which I hypothesised were related to the kind of state in existence. I was particularly concerned to compare states with a strong bureaucracy, but with a specific emphasis on social development and a democratic structure, with authoritarian states with bureaucracies enforcing economic development under more ideological models. In the latter there is little space to challenge development through the ballot box, direct action, or 'deliberative democracy' with a shared dialogue between representatives. This helped in the identification of India as a failed developmental state and Zimbabwe as first an authoritarian and later an under-developed state. I also

looked for a state with a high dependency on local decision-making where traditional local elites were powerful and there could be multiple local allegiances shaping and constraining action - a weak state - for which Yemen was a good example. I considered these contexts to be significant in how actors in scientific and local elites, and agencies for planning, implementation and management play against each other as well as water users to direct rural transformations and water management in droughtprone areas. I considered that such agency would be shaped by the wider structures and level of concern for development processes emergent in these different kinds of states. I also considered these types of state to be present in a number of developing countries, such that the analyses given in this study had wider relevance.

- They were countries where my own work has been involved with development questions and programmes in water management, but also in quantitative as well as qualitative analyses that examined and suggested reforms to scientific and technical norms being referred to for development planning and intervention in water management. I had always worked with a wider reference to international development policy and programmes, given a longterm concern and interest in the relationships between water and rural development. The development transformations of particular focus for me were reduction in vulnerability and increased livelihood security for small and marginal farmers (as defined locally) - through technologies that were also environmentally sound, and resources management systems and development processes that also built local public capabilities for reflective and participatory design and action. Beyond this problem-oriented approach of what to do, I was concerned to understand how and why the knowledge of engineers, scientists and

interdisciplinary thinking is significant in social change, and how such thinking and teaching needs to evolve. I built my research and networks through proposals, university collaboration and project work, trying always to link with agencies at work in that field. The wider focus and context of my research did change as development initiatives around vulnerability reduction and livelihood security themselves shifted through different emphases. These gave me different perspectives and possibilities for critical investigation of norms in science, technology and agency in these different contexts. Policy debates on rural transformation that shaped these wider contexts of my research included: agrarian reform and agricultural intensification, supporting basic needs, poverty alleviation, sustainable development, decentralised water management and the debate around efficiency and equity in water management (Vincent, 2003, 2001; Hasnip et al, 2000; Groenfeldt et al, 2000). My concern was also for critical development of ideas and skills - for myself, students and research partners - that increased capabilities to understand the relationships between society-resources-technology in public action.

- That the comparative research could also contribute to understanding about agency and knowledge, but enable critical reflection on science and technology and maintain critical support on them as a focus in public action. There have been changing views of science in its contribution to society. These are expressed well in the models of Funtowicz (2000), showing shifts from 'expert demonstration' to 'post-normal science', through the stages of the 'modern model', (where scientific facts, that were unproblematic, could and would determine correct policy); the 'precautionary model' (recognising that scientific facts were neither fully certain or conclusive), and the 'abuse of science' model

(recognising social and political forces in science and its use). I had research and project studies from India, Yemen and Zimbabwe that allowed a study of the relationship of science, technology and agency in public action related to drought and scarcity. I wanted my research to support reflection on how I myself had moved through these models, but also how public agencies could transform (or not) given the changing debate around knowledge in and for public action.

1.5 METHODOLOGICAL DESIGN

The research questions are answered through a set of case studies demonstrating a variety of contexts, as a theoretical replication. The differences include:

- different nation states with different state-agency-community relations that also have different interactions in water resources planning and engineering for development, and different local polities having jurisdiction over administrative, judicial, legislative and technical elements of water development and use;
- different droughtprone locations and different water sources (rainfall, groundwater, springs, river flow) analysed by different methods;
- different water extraction technologies (wells, cisterns, river diversions);
- different conceptual perspectives behind research design (instrumentalist, political economy, cognitive).

All the case studies were originally individual studies: superficially all involved similar study of the scope of the water resource base, and ‘appropriate’ scientific and engineering analysis in development intervention to develop water systems, in regions experiencing periods without rainfall whose length and timing was also uncertain.

However, this is no literal replication. Each gradually starts to show the exploration of wider social and environmental forces mediating water scarcity, contact with wider sets of agencies and field realities, and changing understanding of agency-people and state-locality relations in technology development and water use. Thus, they illustrate my changing cognition of water-technology-society relations over time in how I progressively looked (or was forced) to understand these wider influences.

Five of the case chapters derive from research studies, and previously written texts were revisited for the study in a form of hermeneutic examination, while one has retrospective reflection on a development intervention in which I worked (Yemen). One study was specifically set up for this thesis, to revisit the DPAs of Andhra Pradesh and Maharashtra in India twenty years or so after earlier studies (Chapter 5).

The data sources and research methods used are detailed in Table 1.1. The scale of study, data sources and analytical methods differ across the chapters. Chapters 3 and 4 are really regional surveys, where 'What and How'-type questions (Potter and Subramaniam, 1998) were asked. They draw on archival data, statistical analyses, surveys, semi-structured interviews and basic modelling work. The more recent studies shift to 'What and Why' questions, where case studies are used, with field interviews, field measurements, statistical analyses and design experiments. Thus I describe this thesis as having a meta-framework in its use of methodological tools, in that it uses an interplay of quantitative, ethnographic and 'dialogical' (Fals-Borda and Rahman, 1991) or group research methods. Their balance of use differs strongly across the chapters, showing how my own cognition changed - not only in how I recognised their value, but also in realising the importance (and difficulty) in triangulating between them for verifying information. Chapters 3, 4, and 7 use statistics and records from the public domain. Chapters 5 and 6 involve my own field data alongside available public records.

Table 1.1 Research activities and data collection

Study	Questions	Date	Location and research base	Fieldwork period	Methodologies of investigation and data sources
Maharashtra, India (Chapter 3)	What and how	1978		5 months	Regional survey of droughtprone area archives (Rainfall records, government statistics, reports) Statistical analysis of rainfall records (1901-1975) Simple agro-meteorological modeling
Maharashtra, India (Chapter 5)	What and why	1992 - 2002	Meteorological Dept, Pune	Consultancies, brief visits	Interviews with agencies, NGOs
Andhra Pradesh, India (Chapter 4)	What and how	1983	Rayalaseema region Kurnool district office	6 months	Regional survey of droughtprone area/district Archives (Government groundwater and well records, reports, financial files) Simple groundwater modeling Semi-structured Interviews with agency staff and farmers
Andhra Pradesh, India (Chapter 5)	What and why	2002	Kurnool district	3 months	Case studies: villages in different geological areas Surveys (Rapid rural appraisal) Archives (Government reports, surveys of wells data) Semi-structured interviews with agency staff and farmers
Yemen (Chapter 6)	What, how and why	1985 - 1987	Raymah district	2.5 years	Case studies: village and water systems Surveys (hydrology, site surveys, households) Experiment, simple modeling (system design) Semi-structured interviews (agencies, representatives, household/ irrigation users) Meetings Interviews with agencies, political representatives, farmers
Zimbabwe (Chapter 7)	What and why	1997 - 2000	Lower Odzi watershed Manicaland Province	Typically two visits a year, 2-4 weeks each	Case study of a watershed Archives (water rights. legislation) Statistics (River flow records) Surveys (Field transects, irrigation system visits Interviews (scientists, managers)

1.6 CHAPTER PLAN

Chapter 1 has introduced the research questions and methodological approach of the thesis. Chapter 2 provides the theoretical framework

Chapters 3-5 focus on studies from India: an intermezzo chapter first carries brief details of the Indian planning system, and core agencies and programmes working in the drought prone areas. In this thesis I characterise India as primarily a failed 'developmental state' with strong distributive (patronage) policies that nevertheless allowed a strong role to private capital and markets. This has tended to give free rein to technological policies and public agency in which science is accorded a critical role (but poorly performed), but which nevertheless generate real problems of access (worsened by corruption), and have little scope for coercive control to manage water even if laws are in place.

Chapter 3 reviews both agency practices and alternative analyses for the study of meteorological and agricultural drought as applied in the drought-prone area of Maharashtra (DPAM). It involved analyses of meteorological data at 22 stations across the region for the period 1901-1975, to explore analytical methods that might support development planning in the DPAM. I was largely urban-based working with the records of key agencies, although I had meetings with regional agricultural research stations, NGOs and district development agencies, and made some field visits to water management projects. A critical finding was that, where statistical patterns in rainfall were visible, farmers had already started experimenting with new crop options to match them. Statistics validated what farmers were already doing, rather than helping to define spaces for new technology development - and many factors besides rainfall explained dynamics of rural transformation. I knew this by the end of the research - but

the study had no impact. This was because I did not link at all to real social questions. My findings validated other experts and had little power to threaten them.

Chapter 4 documents research on groundwater development in the droughtprone Rayalaseema region of Andhra Pradesh state from 1984, in Kurnool district in particular. It studies both the practices of technoscientific agencies and their performance in the DPA. I located myself at the district level, and used secondary and grey literature from reports and files, and also field visits to villages 'benefiting' from groundwater development programmes. This study required some detailed geohydrological analysis and comparisons of yield calculations. Major expansion of borewell technology was then just starting, but this expansion was first driven by agencies and subsidies rather than real technical advantages (after resultant falls in groundwater levels, this changed). Under-reporting of well development was rampant. I found myself looking at major corruption involving fictitious and partially developed wells. My research in this case had implications, and both I and my assistants had some unpleasant experiences as a result.

Chapter 5 revisits Maharashtra and Andhra Pradesh and the agencies earlier described, to see how they changed in the decade 1992-2002, and what new policies and assessment procedures came on line. By this time, the policies and agencies produced by the instrumentalist efforts to mediate drought were being publicly questioned, and new frameworks of scarcity were being used by other actors (notably NGOs and local government) to identify new support options. Political lobbying for drought relief and irrigation water allocations had proved to be as important as linearly-directed scientific and technology dissemination in the survival of many (Mathur and Jayal, 1993; Omvedt and Patankar, 1991). It also reports a study in three different groundwater zones across Kurnool district in 2002 that examined local experience and

change and indigenous understanding of drought and scarcity. Both collective experience and contact with new actors had greatly changed the resultant public reflection. Detailed knowledge about water resources and technology was only partly important: rather it was also strategic knowledge about which public agencies to lobby and interact with that also mediated access to water. This fieldwork was 'dialogical' in the way it used interviews and rapid rural appraisal (RRA) methods. The Kurnool village RRA was undertaken in 2002, in villages also assisted under a Dutch-supported development programme in which other Wageningen students had been active. After initial contact with the project, I continued to work independently with a local assistant who had once worked for the project.

A short 'Intermezzo II' then follows, to describe the very different agency contexts for two subsequent case studies on Yemen and Zimbabwe, which also focus on different hydrological environments and forms of drought-proneness. These chapters are also written to bring perspectives from scarcity analysis and drought together. This gives a stronger social and political focus – in identifying who was excluded and how under physical and structural water scarcity – alongside discussion of parameters used for the physical description of drought and shortages, and potential changes in the framework for hydrological analysis.

Chapter 6 presents a study from Raymah district of the then Yemen Arab Republic (YR), where I worked two and a half years (1985-87) in a drinking water project. This was an area of limited water resources already heavily developed for irrigation. I characterise YR as a weak state, where the central state was still hardly present locally in water governance – although it was reshaping the local government system, making this a crucial time in changing water control by local elites. This research can be described as exploratory action research, with extensive field contact with local

officials, villages and counterparts to examine a complex hydrology and even more complex system of customary water rights. The study focuses on groundwater-based spring development and small-scale water harvesting. The critical struggles were around social jurisdiction, challenged by the new water technologies and design and assessment techniques arriving in the region. Villagers used the project to test the changing authority and contest an older legal ruling on water resources they felt unfair. Technology became the battlefield where water rights were contested, and the battle ended the project.

Chapter 7 presents a study from Zimbabwe, 1997-2000, focusing on the assessment and management of rivers subject to drought events and low periods, in the Lower Odzi watershed. I describe Zimbabwe first as an authoritarian and segregationist (racist) state, that was directive but not particularly corrupt, later becoming an underdeveloped state experiencing corruption and elitism. The agencies under these authoritarian governments have been very different, employing legal agency (in a Water court) under quite a highly developed legal codification, as well as a scientifically elite Ministry for water planning and monitoring. The study used archival material on legal developments and rights, hydrological data sets, and some field data, including some feedback from PhD research studying smallholder irrigation systems in the same catchment. The study shows how assessment practices and access benefited the interests of commercial (white) farmers, with little analysis that showed the problems of smallholder water users.

Chapter 8 presents the conclusions of this thesis. The thesis shows that science has made considerable contribution to understanding of drought in its various forms, particularly through the ways it has enabled patterns to be identified. Yet it has not made the contribution to either sustainable technology development, or effective

agency for sustainable resource use and congruent technology choice and operations that many hoped for. The nature of the state does make a difference to the institutions and public agencies that evolve for monitoring, planning and implementing water development in droughtprone and scarcity regions. Commonly, within these agencies there has been failure to transform the norms in its own institutions and liaise across different agencies, and lack of engagement by agencies with their publics over the complexity of technological problems and related development questions for droughtprone areas. In failing to reform cognitive and institutional norms in the pursuit of daily institutional life, these public agencies have often lost some of both their power to contribute to resolution of complex water problems and their power over new policies, while their norms may lead to confusion and lack of clear application, allowing unequal and inequitable access to water resources.

CHAPTER 2

CONCEPTUAL FRAMEWORK

'Given the idiosyncrasies of science, it is practically impossible to make any science to order for technology. There is therefore no gain in coupling the two together...there are even disadvantages from doing so...New technology, in order to be achievable must use known, existing science and set itself, short-term, precise goals of achievement. There is very little evidence that the emergence of new technologies is critical to any process of redistributive justice in any direct fashion...At their worst they are easily turned into tools of exploitation because of this amorality implicit in them... The development of new technologies, regardless of how important to national hubris, is not critical to development'...Rath (1994). p. 2916-2919

2.1 INTRODUCTION

This chapter sets out the conceptual framework for this thesis, which builds first from the observation of Benton (1992, p. 67) that technology is a mediation between social relations and natural mechanisms. He argued that technology is a critical tool in this mastery of nature, but also emerges under particular preferences for, or imposition of, structures and processes of social control. The social relations and structures of special focus here are: the state as it affects the processes of development, public agencies as part of public action, and the knowledge systems and cognitive frameworks that evolve within these agencies and states, discussed in turn in sections 2.2-2.4 respectively. The natural mechanisms focused on in this thesis are the sub-cycles of the water cycle – precipitation, soil moisture, groundwater and surface water as shaped by natural drought – periods without rain - and human intervention through technology that has led to declining storage potential, more erratic behaviour and overexploitation of these water resources. In focus too are the scientific specialties developed for these water elements – agro-meteorology, hydrology, geohydrology and farming systems research. These are reviewed in sections 2.5-2.8. The remainder of this section reviews concepts for technology and science used in this thesis. Figure 2.1 summarises this conceptual framework.

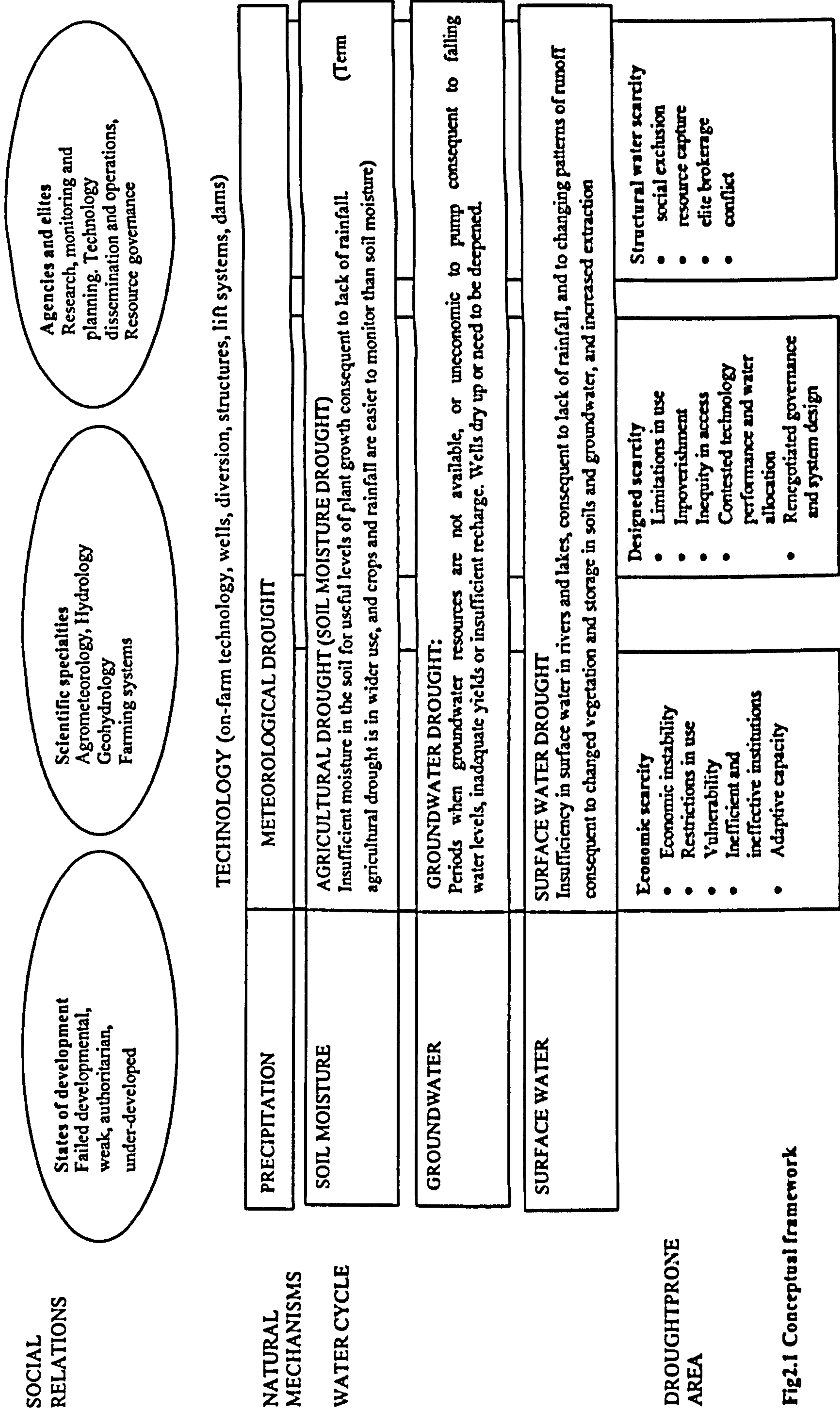


Fig2.1 Conceptual framework

This differentiates the behavioural characteristics of natural phenomena of precipitation, soil moisture and vegetation, groundwater, and surface water as they materialise in drought, with different relational dimensions of scarcity – economic, physical and structural water scarcity.

Focusing on technology as a mediation, something imposed between society and resources, enables a critical focus on agency to mobilise and manage the resources and build institutions to govern resource access, and the cognition used for this, including the framing discourses that shape emergent roles and practices, and the cognitive and technical norms developed. The option to look at emerging water deficits as scarcity, in which society develops coping strategies around the technologies giving water access, and not just as drought is a further cognitive transformation made easier by recognising this mediating role of technology.

I use three other associated conceptions of technology to open up this study. The first is to see technology as ‘the invention and employment of artifacts’ (Feibleman 1982), where artifacts are materials altered through human agency for human use (artifacts may be tools or language). The second is to see technology as ‘artificial function’ (Nightingale, 1999). This definition allows study of the cognitive dimension of tacit knowledge – in how artifacts should and can function, as opposed to just factual knowledge of intrinsic properties. This tacit knowledge exists within a technological tradition that co-evolves with a technology (which also may not involve much science), and a group’s perspective on the relationship between nature and society, and appropriate technology (Dosi, 1982; Richards, 1985). This helps in understanding different views about how technologies can be changed, as will be discussed particularly in the Yemen case. A third is that cited by Peilke, 2003 p. 311 of ... ‘Winner’s concept of ‘technology as legislation’ ...as an interpretive tool for understanding of the meanings that drive people to favour certain choices of

technological systems over others... and a malleable base value in policy debate, and around which ideas, interests and institutions are created, marshalled, diffused and restricted'. These related conceptualisations allow study of the knowledge, institutional control and coping strategies involved in the development and operation of technologies for different water resources in a drought-prone area.

I also draw on several conceptualisations of science for this study. Feibleman (1982) saw 'pure science' as a method to investigate nature by experimental methods, while applied science was the use of pure science for practical purposes. When 'science' is used to address public policy needs (Healy and Ascher, 1995), science is rather a body of empirically-derived routines, often seen as 'disciplines', allowed into policy debate because of their supposed scientific credentials and objective methods, free of the 'moral hazard' of subjective description. Nightingale (1998) defined science as the social practice of exploring and codifying patterns¹ in the behaviour of nature. Rath (1994) saw science as exploratory activity, less concerned for facts for 'knowledge', and more a search for 'models' of the world and how it works, that was often just information gathering rather than science. Given the dependence on technology of contemporary scientific research, Latour (1983) introduced the term technoscience for the complex world of contemporary investigation and deployment of science in technology creation.

A core focus in this thesis is on the use of statistics, which has become regarded by many as a quantitative science because of its evolution from application of mathematics and logic, such that it can describe the 'physics of society' (Funtowicz and Ravetz, 1990). and thus produce facts for policy conclusions. Others are more pragmatic,

¹ These can be patterns: in the behaviour of natural phenomena; mental links between patterns and our sense experience; using mathematics as a shorthand for patterns that also compress information about behaviour.

recognising that statistics cannot provide facts but only forecasts, predictions and risk assessments (Funtowicz and Ravetz, 1990, p. 156), that have their own historical ontology (Hacking, 1990). It is the construction and application of statistics and data analysis in planning and decision-making, that much of this thesis is concerned.

Yevyevich (1985) described risk as the exceedence or non-exceedance probability of a decision value of the critical random variable. However, we could choose to develop additional pictures of risk, for example economic risk, by looking at this probability and the consequences from that occurrence of risk. Risk is defined as related to quantifiable variables, in that their randomness is known and they can be measured. Later sections review how different researchers and agencies began to shape understanding of such risks in relation to water users for the different components of the hydrological cycle, relative to current use of technology and benefits from change. Uncertainty, has much less uniform definitions, but is often defined as related to non-quantifiable phenomena, described as such because of the complexity, non-randomness or unpredictability of their behaviour in space and time. Three forms of uncertainty identified are description uncertainty, parameter or measurement uncertainty, and natural uncertainty (including climatic, environmental and societal changes). Klemes (1985) voiced concern over preoccupation with 'creation of curve-fitting tools' in stochastic hydrology, rather than attention to methods and contexts for application of tools to improve management decisions. Controversy around how complex phenomena are described to enable quantification, and whether they are then studied through appropriate statistics, has become a serious question in the validation of science and its wider social legitimacy.

Funtowicz and Ravetz (1990) went on to discuss several ways in which statistical analysis of data sets had critical differences from experimental research. Their significance can change depending on their temporal and spatial density. Evaluation of

the truth of information or procedure is done by review procedures (internal or external), rather than by scientific colleagues. In addition, behind the concern about how risks and uncertainties are treated, lies the question of quality of information to which statistical tools are applied, and how these come from experiments, as opposed to data collected in society for 'statecraft' and even personal judgements. In the latter case, the data collected could become shaped by the mission of the agency collecting it. As will be seen in Chapter 3, some Indian research agencies did try to keep the data used for statistical analysis based field data collection and experimentation. However, other agencies have amassed socially constituted criteria (for example, assessments of levels of crop failure), or data recorded from individuals (like census data). Thus behind the question of risk and uncertainty in availability of water, lies questions about the quality and uncertainty of the data used in its assessment.

Brooks (1994) noted at least six ways in which science could contribute to technology, as: (1) new knowledge which serves as a direct source of ideas (once given most emphasis now often seen as least significant); (2) a source of tools and techniques for more efficient engineering design; (3) research instrumentation, laboratory techniques and analytical methods that find their way into design or operational practices; (4) the practice of research as a source of development of skills and capabilities useful for technology; (5) the creation of a knowledge base increasingly important in understanding the assessment of technology in terms of its wider social and environmental impact; (6) a knowledge base that enables more efficient strategies of applied research, development and refinement of new technologies. Brooks also showed that there were at least two ways that technology influenced science - and that this direction was at least as important in change. The first was in providing a fertile source of novel questions and thus helping to justify resources spent. The second was as a source of otherwise unavailable instrumentation and techniques needed to address

novel and more difficult scientific questions more efficiently. He also warned that some technologies- notably mechanical ones – did not need much science in their development. He also agreed that tacit knowledge was important, and was embedded in people rather than written down and codified. This typology is used to study the analytical routines used in agencies, and identify which actors have real knowledge about the behaviour of technology in relation to the resource base. While science and technology are seen by some as critical tools in social development, they are also critiqued, for being: non-neutral in their accessibility and impact (Knecht and Vincent, 2001); blind to special characteristics of environment and society (Chambers, 1997) biased in its preferences for quantitative data (Lemos, 2003), and used to insulate policy makers from their public and support public objectives rather than determine them (Healy and Ascher, 1995) i.e. socially constructed rather than impartial (Rose and Rose, 1976).

2.2 STATES AND DEVELOPMENT

2.2.1 Development as an objective and process

This thesis studies development as both an objective and a process, as outlined in Table 2.1, and recognises the primacy of politics in both, after Leftwich (2000). He argues that, if we are to understand the different performance of societies (how people cope, what is achieved, what is possible in certain contexts) then we need to understand how their politics condense around their states, and the agencies and elites within them. This is the reason to compare several different states in this thesis.

Table 2.1 Definitions of development and politics

Development as objective (Thomas et. al., 1998)

Progress (material or ideals) through agencies and management for change, given conflicts in goals, values or interests.

Development as process (Leftwich, 2000)

While development can have various definitions, it always involves the organisation, mobilization, combination, use and distribution of resources in new ways....and because resources are to be used in new ways there will inevitably be disputes among individuals and groups about how such resources are to be used as they calculate who will win and who will lose as a result of different configurations

Politics (Leftwich, 2000)

All the activities of conflict, cooperation and negotiation involved in the use, production and distribution of resources, whether material or ideal, whether at local, national or international levels, or whether in the private or public domain.

To look within the state, I use a model by Davies and Hossain (2002) that showed relationships between public action, civil society and livelihood adaptation. They posited overlapping fields of action between state, community and civil society, to enable identification of elites in each that in fact brokered or captured most of the spaces where state action programmes and people interact. However, there was a space where all did sometimes interact, which could be seen as spaces for participation and interaction that could enable negotiation and change. The process and style of exchange was, however, shaped by the wider history of state-society relations. There were also multiple locales of action, including civil society action (formal and informal), beyond the arenas of state agencies. Formal civil society groups included cooperative societies, self-help groups, and social movements, which can have religious, spiritual and philosophical ideas and values at their core. Authors like Dubash (2002) and Steenbergen (1997) argued that we should take a more realistic view of local agrarian institutions as they emerge in different cultural, political and ecological contexts, to understand whether local institutions would perform better than public agencies in mediating scarcity, especially in management of groundwater.

Development intervention is one stream within public action, in its pursuit of deliberate efforts at social change on the part of one or more public agencies, given public recognition through constitutional approval or legal registration. However, such agencies also intervene in social and political relations, and do not simply implement the plans and contracts issued under a policy or programme. How these agencies face conflicts of values, goals and interests both within themselves and with other agencies, to create effective actor-networks (or not), is of particular interest to this study, especially for the Indian case studies. This can be studied through the coherence (cognitive consistency), with wide acceptance of facts and routines generated and correspondence (good structural coupling). Another component in public action is direct action – actions driven by interest groups to confront issues or drive change considered not addressed by formal public or development action. It can have violent and coercive forms, as well as cajoling ones - including strikes, threats, roadblocks, protests, destruction of water systems and offices, and parliamentary and bureaucratic lobbying. Such action has become increasingly significant in droughtprone areas, as public agencies have fossilised and failed to enable full participation. Like Davies and Hossain (2002) I keep direct action distinct within public action. It is the broader power of the state that often defines how such local direct action is associated with formal public action or not. For example, in Maharashtra, it was the protests and demonstrations of drought-affected farmers that often ensured that food aid rights to which they were constitutionally entitled actually arrived in their village (Ormvedt and Patankar, 1991).

2.3.2 States of development

In his review of states as they have been involved in development, Leftwich (2000) differentiated between their institutional structures, political purposes and development objectives. He built on the concept of the 'developmental state' started by Johnson (1981), which were states with institutional structures and political purposes that were 'developmentally' driven, while their developmental objectives were actually 'politically' driven, in terms of fundamental political factors driving the urgency, nature and pace of development actions. They were also states that have concentrated sufficient power, autonomy, capacity and legitimacy at the centre to shape, pursue and encourage achievement of explicit objectives (Leftwich, 2000, p. 155), and new technologies and major technological projects might even have symbolic value for the nation state. He also confirmed what Johnson (1981) noted, that developmental states had a strong intimacy with the private sector and the market, and a further feature was the power, continuity and autonomy of its elite bureaucracy. Having said this, none of the case studies discussed in this thesis now meet all the criteria of a developmental state.

How agency develops under different politics with different objectives and purposes and different social relations within them is a core focus in this study. I look at how these political and social conditions shape the emergence of instrumentalist, infrastructure-focused water development – directed and controlled by public expert agencies, versus local, endogenous development and knowledge. Also, how these conditions shape the areas of mediation between society and resources that agencies are directed into – in new scientific research, collecting data for resource assessment and planning, disseminating and managing the technology, and creating governance institutions that control water access.

States of development: India, Yemen and Zimbabwe

Herring (1999) regarded India as a failed developmental state, hamstrung by size and the pressure of interest groups into politics. Nevertheless, the case studies from India will show many of the structural institutions and imperatives taken up by 'developmental states'. Myrdal (1970) regarded India as a 'soft state', with a lack of social discipline at its core in which reluctance to abide by rules, corruption, and collusion of interest groups and elites allowed avoidance, blockage and subversion of development programmes. However, India most certainly is a democratic state², which has helped maintain civil society and human rights action that counteracts some of this bureaucratic power. As chapters 3-5 show, these characteristics do materialise in the agencies for the droughtprone areas of India, but also often render them ineffective with little or even negative impact. For the states and time periods studied here, only India formally developed a Science and Technology Ministry, and developed agencies to disseminate particular artifacts (see chapter 4 and 5).

I describe Zimbabwe as a past authoritarian state with segregationist and racist policies, but actually not corrupt, that has now become an 'underdeveloped state'. Authoritarian states can put specific and strong legal codes and agencies into the control of resource access, in contrast to developmental states which can often leave the market to broker resource use. An underdeveloped state is one characterised by inefficiency and instability, with wealth flowing from control of political power and hence control of the state and its organisations. Zimbabwe is also increasingly a patrimonial state, where a ruler attempts to dominate and control in his own interest and

²Leftwich (2000) described the characteristics for their survival to include: legitimacy (geographical, constitutional and political); adherence to the 'rules of the game'; loyalty to the democratic process itself; policy restraint by the winning party; overcoming poverty or continuing to struggle against it; wealth or at least growth that moderates inequalities; and overcoming religious, ethnic and cultural cleavages or continuing to work against them.

that of his cronies. (Leftwich, 2000; Weiss, 1994). I characterise the Yemen Arab Republic, at the time of the case study, as a weak state. Following Migdal, 1988 (p.4) this has... 'low capacity to penetrate society, regulate social relationships, extract resources and appropriate and use resources in determined ways...thus numerous social organisations exercise control, commanding allegiance of significant numbers of people, that may be enduring traditional institutions'. Section 1.4 has given detailed reasons for selection of these different types of state, and I hope that the case studies help show the stresses the stresses on hydrologists and engineers working in them.

2.2.3 On agency in development arenas

Agency is the capacity of an actor to realise at least part of the intended actions through (strategic) interactions in a network of social relationships (Long, 2001): the focus in this thesis on institutionalised actors - individual and collective - that shape goals, values and interests through their deployment of knowledge as institutionalised rules or science in the selection and development of technology in drought-prone areas. Collectivities become agents when they have discernible ways of formulating and carrying out decisions (Long, 2001). Knowledgeability and capability are critical in agency - but need to be translated culturally and politically. While there may be a *habitus*³ in an agency in which its practices are themselves conduits of interest, individual internal and external actors can also reshape these.

Platt and Wilson (1999) have used the term 'technological capability' in terms of the ability to realise technological capacity through performance rather than just the potential of an organisation or enterprise to perform. Their work on micro-enterprises

³ The system of acquired dispositions and habituated practices that act in perception and practical assessment and in organising principles of action (Bourdieu, 1977).

can also be related to public agencies and informal groups, although the greater power of institutionalised control in bureaucracy preventing change needs recognition. How groups are capable of organisational and technological learning will vary according to the socio-cultural context. Researchers have focused on several frameworks to study how a learning cycle can be developed that can confront power struggles and transform practice within organisations. These include empirical learning, learning by emulation and learning by acquisition (Carbonara, 2004), and a participatory process that builds from what people know rather than confronting and criticising them (Platt and Wilson, 1999). Shifts in these processes are visible across this thesis in some of the bilateral development programmes, scientific networks, politicians and individuals (including myself) studied. Interest in these shifts is also a key reason to bring in a cognitive approach to study the dynamics of agency behaviour.

2.3. COGNITIVE APPROACHES TO STUDY AGENCY PERFORMANCE

How public agencies form, perform and reform their scientific and cognitive norms to support social transformation in droughtprone areas, and how science and technology are part of this evolution in rationale and operating procedures - to stay in operation and serve their clients - is a core theme in this study. In their study of cognitive spaces, Jorgensen and Sorensen (1999) built together a number of concepts also used in this thesis. These included 'institutionalised actors' – which in this study are often public agencies but may also be important local representatives, and 'framing objects'. Framing objects include: relatively fixed visions of a technology and its role; or a discourse on roles of communication methods, or modernization aims; or a set of technological concepts created in the education of engineers and the standards operating in an area (Pijnenburg 2004).

Kuhn (1963) emphasised the cognitive consensus that can make up a speciality, which includes common substantive and methodological orientation (Weingart, 1974). He later shifted his term again to that of 'disciplinary matrix', which detailed the entire constellation of beliefs, values, techniques etc shared by a community. Whitely (1974 p.73) used the term cognitive institutionalisation, to describe the articulation of cognitive norms (legitimate problems) and technical norms (legitimate techniques) (Mulkay 1970) which come to define certain legitimate problems and techniques into a relatively coherent mode of understanding. This involves a set of inter-related and inter-dependent (though not necessarily logical) statements about the world and how to study it - and intervene in it. Cognitive institutionalisation also becomes a structuring element in social processes, if a group develops and organises themselves powerfully enough, and uses knowledge for control. This thesis applies these concepts of cognitive institutionalisation beyond scientific specialties, into the worlds of development agencies and institutionalised actors working in drought-prone areas and the 'framing' discourses and approaches they use. Kuhn used the phrase 'normal science' to summarise these internal behavioural characteristics of scientists studying the physical world, in the ways knowledge was allowed and suppressed. Post-normal science was described as field of endeavour by Ravetz and Funtowicz (1999), that could not only recognise a range of new study areas emerging to deal with environmental complexity and uncertainty, but also allowed an extended peer community into creation and validation of knowledge used in public decision-making.

To map the 'cognitive institutionalisation' critical to development action around drought, I follow the idea of Ravetz (1971) to look to see how groups define 'the purposes seen to be served' by intervention in society, and thus start to direct and fund cognition and action, and understand the relation between the two. This is visible in the research approaches, technology development, particular resource analyses, and

assisted development of products and systems these purposes are seen to require, and the scientific, technical and practical approaches taken up within them. I look into the programmes of research, technology development and institutional intervention these purposes have driven, to study what knowledge has actually been applied in research and implementation, or contested by users, and whether agencies change their cognition at all (or not).

Roling (2002 p.32) emphasises the structural coupling in cognition between the perceiving organism and the domain of existence – they are structurally coupled. Thus cognition includes an agent that can perceive, has context - beliefs or theories, emotions and criteria for judgement, relating to the environment or domain of existence the agent is structurally coupled to; and an ecosystem or space in which multiple agents interact. It is important that an agent keeps pace with the realities of their domain to have potential to act – it needs correspondence. The facts, routines and technologies produced and used have to stay significant and remain accepted for an agent to be seen to remain capable and reliable in its domain – it needs to keep cognitive consistency with other agencies and knowledge groups. Thus to transform as a learning organisation needs two fundamental drivers for the cognitive process: coherence (cognitive consistency) and correspondence (structural coupling) (Gigerenzer et al, 1999). The failure to recognise and adopt these drivers is particularly significant in the fate of the Indian groundwater agencies discussed in Chapters 4 and 5. Roling (2002) also distinguished collective, distributed and multiple cognition, to emphasise the different social relations in which agents have to interact for concerted action. This is relevant in explaining the fate of participatory technology development initiatives discussed for India and Yemen in Chapters 5 and 6.

To explain my own learning, I look beyond the disputed arguments of behaviourists on how the brain works⁴. I draw on the ideas of the French philosopher Bernard-Henry Levy who relates understanding with how we move and travel – in conscientisation and not just space. We never have a blank mind, and have pre-formed views or at least a mass of views: however, learning from heterogeneity and otherness changes us, and thus changes how we act to maintain freedom for ourselves and for our collectivities. This is where ‘accountable participation’ becomes important – otherwise the use of facilitation tools for their own sake is not only a tyranny (Cooke and Kothari, 2001), but a danger.

Other ‘frames’ and discourses on the relationships between society and natural resources that have shaped water development include seeing drought as:

- a causal control on social development. This breeds instrumentalist approaches, in which construction of supply systems for extraction and control of water are dominant concerns;
- a factor in socioeconomic activity. This brings modelling and rationalist approaches to design of technologies and institutions aiming at profit as much as sustainability;
- a reactive phenomena from society’s use of the environment, in which ‘resource dilemma’ assessments and social learning processes are core tools for transformations.

My own cognitive history is greatly bound up in my own movement through these cognitive perspectives on the relationship between society and nature, and within this on drought and development. However, at the end I stay with the view of Benton (1992), that public action in a drought-prone and scarcity area can only work for a greater good if it is constantly aware of the struggle in mediation around the design,

⁴ i.e. whether our minds are virgin spaces that develop tendencies in relation to the teachings of our culture, or whether there are brains with a predilection to think in certain ways and thus get drawn to certain work, disciplines and ways of thinking.

operation and access to use of technology. This means awareness of these discourses and their concerns about technological and resource risk and uncertainty, and reflection and action about the data and analytical routines used within them.

2.4 DROUGHT, DROUGHTPRONENESS AND SCARCITY

Drought is a period without rain, specified as of human interest in how this dryspell affects agricultural production, and as societies have transformed on the activities of society in the affected region. Wallen (1967) distinguished between permanent drought (of the driest climates), seasonal drought in climates having well-defined wet and dry seasons; and contingent drought resulting from irregular and variable rainfall. Dry periods bring impacts to regions and not only to individual fields, and the term 'droughtprone regions' has been in existence since the nineteenth century in India. 'Droughtproofing' emerged as a term to describe actions and measures that could make societies better able to survive drought. Drought and scarcity have come to occupy public debate in ways that other criteria like dryness and aridity never have, perhaps because of the way they link into public interests and possibilities to reduce calamity and vulnerability, rather than the struggle to build new adaptive capacity in resource management. Yevjevich et al (1983) developed a matrix to study 'dryness' differentiating nature-produced and human-produced conditions. Drought and aridity were nature-produced, the terms representing temporary versus permanent shortages: water shortages and desertification were human-produced. The case study areas show different degrees of dryness and aridity, interacting with seasonal and contingent drought, and give more chance to study cognition in agency around these ideas.

The meteorological phenomenon of drought brings perturbations into the soil moisture availability, rivers and groundwater in the hydrological cycles of a region.

Hladny and Buchtele (1989) differentiated agricultural drought – linked with soil moisture content and slowed growth or even death of plants – from hydrological drought – where the diminution of water flow and storage is critical as in surface, sub-surface and ground water.

Bandyopadhyay (1987, p.2159) noted that 'drought has generally been associated exclusively with deviations in rainfall. In actual fact the current water scarcity is a result of our failure to ensure the stability of the water cycle in the course of implementing development programmes'. Bandyopadhyay differentiated between soil moisture drought, surface water drought, groundwater drought, and man-made drought, wanting to widen the debate to incorporate the technology being disseminated in development programmes. He pointed out that this caused 'man-made drought' to occur even in years of normal rainfall, referring to water overextraction and thus drying-up of older water sources. He launched a call '... to look into the reasons for other forms of drought that actually represent water scarcity, instead of putting all the blame on the failure of rainfall in an unscientific manner ...'(p.2180). He called for a shift to frameworks that focused on the overall water cycle to resolve scarcity and promote environmental recovery, away from the normal focus on water inputs into particular crop and human use systems.

Mehta (1998) showed how concepts of scarcity enable a focus on relational aspects of the use of water. She distinguished between the constructed aspects of scarcity – in what discourses were permitted – and the physical realities of declining access and use, noting how the former obscured the diverse strategies and different knowledge that local people used in the face of limited sources and restricted access. While the underlying power and social relations shaping discourses remain unchallenged, water use and access will remain unequal and policies be flawed. Mehta's work is important in this identification of this construction, but leaves the risk of destroying the value of

scarcity as a focus in public action, and a loss of understanding of the historical dimension critical to this public action. The portrayal of shortage also has preferred if not sanctioned discourses, which have been used particularly in tools for scenario planning. However, these also have weaknesses in their portrayal of local people's access and strategies and options to change them. Indices of per capita water consumption (Falkenmark, 1990) and water scarcity and productivity (Seckler, 1996), and concepts of transformations to 'closed basins' where all water is allocated and used (Keller et al., 1997), are all abstracted from the everyday reality of people's access water unless they also address the policies of the states they operate within.

Historically, the drought-affected areas of India were known as scarcity regions, because of their lack of options and investments shaped by the uncertain and limited amounts of rainfall (Government of Maharashtra, 1973). Even before Mehta, there were calls for a wider perspective on how human agency was involved in or affected by drought and scarcity. Sexton (1992, 1990) distinguished 'economic scarcity' as scarcity related to economic development choices that generated institutions that first help but eventually often constrain access to water, as opposed to absolute scarcity which he thought technology-limited. These institutions relate to wider economic decision making which often can get captured by water institutions set up. Homer-Dixon (1995) described 'structural scarcity', that evolved from the process of 'resource capture' by powerful groups, that will be seen in the Zimbabwe case study. Turton and Warner (1999) differentiated orders of water scarcity, with first order scarcity measured in resource availability, and second order scarcity was scarcity of social means - adaptive capacity and social resources to act resolve emergent competition and conflict. I keep this concept related with economic scarcity. I study these realities for India in Chapter 5, Yemen in Chapter 6 and Zimbabwe in Chapter 7.

Ohlsson and Turton (1999) portrayed a historic spiral in water management approaches, where action started with engineering efforts to liberate supplies but transformed into different agency needs to manage demand and access transformed by this liberation - in which it became more and more difficult to separate natural droughts from socially conditioned scarcities because of the technological dimension. Eventually natural resource reconstruction was necessary demanding social adaptive capacity which could be both endogenous and externally supported by projects and capacity building. A problem with this spiral concept is its looseness in articulating the struggle in transformation of institutions and the initiatives that might build this social adaptive capacity. Sexton (1990, p. 24-25, citing Galnoor, 1980) also criticised 'supply-side approaches' that evolved for a historically specific task of opening up water supply. However, he noted that while this produced clearly visible water institutions, it actually left de-facto water-policy decision-making in the agricultural sector. This meant that both old and new institutions assumed best able to meet a task would have difficulties achieving adaptive capacity on any-prefigured norms unless they also had real understanding of agrarian and economic dimensions and processes of the agricultural sector. Sexton, together with writers like Allan (1993) looked for demand-side conceptual approaches to assist understanding of scarcity and policies for its management, focusing onto allocation. Allan emphasised allocative rather than technical efficiency in resolving scarcity, particularly developing the 'virtual water' concept that estimates the water value of imported products against locally produced goods. Allan (1993) also emphasised that such concepts should be used alongside effective political discussion about food sufficiency and livelihood security in economic planning and not be reduced to a de-politicised tool. However, concepts that bring this debate to the local reality of agrarian conditions and agricultural sectors are rare. Adaptive capacity, without a sound base in understanding of local agrarian politics

and natural resources, can become another target for generic models and pre-figured tools of intervention and capacity building. Much of this thesis is written in the hope of emphasising the importance of understanding the interplay of state, locality and rural transformation in resolution of scarcities and reduction in vulnerability to drought.

From within research on users of water, some authors have attempted to conceptualise water scarcity for use in irrigation (re)design and operations. Wade (1988) opened up initial understanding of the role of local agrarian institutions in mediating water scarcity as also shaped by technology and resource contexts. Uphoff et al (1990) differentiated relative and absolute water scarcity in system allocation and delivery. In the former overall supply left room to manoeuvre, such that actions by one farmer or a group could also reduce the problems of another, giving a role to local irrigation management institutions. With absolute water scarcity, water delivery could only be enforced and mediated by strong authority. Mollinga (1998) and Oorthuizen (2003) opened up these concepts further by exploring the interplay of water technology, water delivery and key actors. Mollinga (1998) explored how scarcity was also actual a design choice under supply-side policies, constituting its own evolving array of political and technical actors in water delivery - who also could also constrain reforms to deal with changing demands and agrarian conditions. Oorthuizen (2003) explored local scarcity constrained by policies of allocation as well as technology design choices, in irrigation systems with areas given core and peripheral status in security of supply. There, frontline workers and politicians operated alongside recognised but largely powerless local water associations to capture water in particular sites and broker water delivery in highly informal but locally-understood ways. Van Halsema (2002) introduced the idea of the 'irrigation concept', where design choices about technology and institutions need consideration together with a recognition of local agrarian and agricultural realities and their transformation. This can be used to understand problems

water access domains built in at local level, and the real efficacy of new modernisation efforts built around specific technological or institutional transformations. The work of Mollinga (1998) and Oorthuizen (2003) showed the working of political economy between state, technology and resource access needed to use further the concept of 'economic scarcity' as understood by Sexton (1990) and the Maharashtra government (1973), and the structural scarcity of Homer-Dixon (1995).

These concepts inform the framework shown in Fig 2.1. I look at the domains of drought that have received successively more attention as technology has been developed to create more security in water use. I keep contexts of drought related to use - agricultural, groundwater and surface water drought - and investigate how both natural and human factors shape these cycles, as dimensions of scarcity. My own view is that there is a groundswell now to bring together frameworks to study drought and scarcity (see Chapter 5 and 7), and that can be the next cognitive step in relating science, technology and agency in drought-prone areas. However, the case studies will also show the struggles and dilemmas in creating such new public action when older public agencies have evolved with other frameworks. As Ohlsson and Turton (1999) suggest, specialty scientific areas have grown to define the behaviour of different parts of the water cycle and risks from drought, and been linked with agencies developed to manage these water resources and disseminate technologies to use them in drought-prone areas. However, these initiatives create new pressures of scarcity that are rarely addressed through existing specialties and agencies, leaving problems of coherence and consistency. The remaining sections of this chapter now review core knowledge research developments in each drought context, in relation to both the nature and impacts of drought and scarcity.

2.5 AGRICULTURAL DROUGHT

2.5.1. How do producers survive in a droughtprone region?

Morris (1974) used the question 'What is famine' to draw out the aspects of the production cycle which enabled people to live in an area with a recognisable risk of rainfall failure. Famine is associated with drought, but is not a direct consequence⁵. The effects of inadequate rainfall in any one year have to be seen against what is 'normal' for such an area. One important concern was the impact of sequences of bad years, in addition to a high frequency of individual bad years, which lay at the root of a constellation of problems of underinvestment, risks and losses, and general low yields from poor soils and low-level moisture-fertility responses. Runs of dry years were seen to have particular impact, in how farmers could lose productive assets and savings, and face severe problems in restarting after drought (Binswanger et al, 1979; Jodha, 1991). Recognising traditional coping mechanisms, but also finding new ones, became a concern of some for research in the droughtprone areas (Dandekar, 1976; Jodha, 1991).

However, by the mid 1970s, after serious droughts in India, others pointed how older coping mechanisms were breaking down. Agarwal (1991), Borkar and Nadkarni (1975), Moser (1994) and others studied how households coped with different vulnerabilities⁶ related to seasonality and actual calamity, and how they drew on income, social relationships, collective resources, migration and sale of productive and non-productive

⁵ Famine, which has attracted a huge literature, could be created by war, a range of disasters or even simple hoarding that changed people's access and 'exchange entitlements' (Sen, 1992).

⁶ Blaikie et al (1994) defined vulnerability as '*a combination of characteristics or group expressed in relation to hazard exposure, which derives from the social and economic condition of the individual, family or community concerned.*' (p.60). Both Blaikie et al (1994) and Moser (1998) emphasised how vulnerability is different from poverty, and that there were policy reasons for keeping them separate: anti-poverty programmes were designed to raise incomes or consumption, while anti-vulnerability programmes aimed to reduce the chances of the hazard having a negative effect.

assets to survive. Binswanger et al (1979) showed the increasingly precarious position of a farmer as successive droughts hit, in relation to his/her equipment and financial resources. Research showed the slow reinvestment after drought in both productive (livestock, equipment) and non-productive (jewellery, artefacts) assets, and the persistence of indebtedness, with assets rarely being replaced within two years. Not only was the farming system weakened in a drought year, but a real disaster occurred if two or more drought years occurred in succession. Farming systems research became concerned not only to design new production systems that could use new HYV seeds and water sources. They also tried to find strategies related to the risks and options available to small farmers in dry areas: including:

- i) risk reducing measures. These operated before harvest failure, and included crop diversification, intra-seasonal adjustment of sowing times, and soil and water management;
- ii) loss management. These dealt with the consequences of crop failure, and included inter-year storage build-up and resale of assets, salvage operations, borrowing, and insurance;
- iii) off-farm strategies included migration and involvement in drought relief work.

While research under the hazard and calamity frameworks destroyed any romantic notions of easy coping (Blaikie et al, 1994), Morris's (1974) arguments against seeing drought as a special 'hazard' still has value. In a calamity framework, it becomes possible to treat drought events as a one-off occurrence in time, and not part of natural fluctuations. It can encourage people to see the potential resource base as somewhat better than it is, to focus on 'average conditions' against which a drought is a hazard. It can reduce attention to the general environmental base and technological paradigms and collective organizations relevant to this, in favour of an over-emphasis on individual strategies and loose situational mechanisms of coping.

2.5.2. Studying agricultural drought risks

Framing of the 'problem' of droughtprone areas shapes the emergence of data collection to support public action. Only India among the case studies has a historic public interest in agency for drought and scarcity management. Under the colonial administration, drought was interpreted in production terms, by their impact on crop yields and thus on taxes and food supply: thus rainfall and annewari declarations (tax relief allowed relative to yield reduction under calamities) were regularly recorded.

However, globally emerging science networks – under the European empires, the Commonwealth, the UN and CGIAR system post World War II (WWII), and growth of new universities and international assistance programmes – soon helped the expansion of two scientific specialties in particular – agricultural meteorology and agricultural/farming systems research.

Although agro-climatology had its roots in the 19th century, it boomed in the 1950s with advances in weather reconnaissance, understanding of plant photosynthesis and respiration, and plant genetics. Also in the 1950's, Penman and Thornthwaite published their respective formulae for calculating evapotranspiration. These formulae gave scientists their first sense of 'universal' formulae, which could be used for international comparative work.

As the knowledge base grew, both about weather but also about possible new cropping technologies, so too did attention to both risks of unwanted weather conditions, and the reliability of occurrence of weather conditions relative to the needs of new varieties or intensification of cropping. Three particular streams of work emerged that will also be seen in this thesis. However, these also developed rather differently in different regional networks of agricultural research in the indicators selected to help determine public action

Also, the probability levels for which risks were assessed often differed slightly, partly as a result of existing social norms, and related sets of scientific activity.

One stream of research followed emphasis on the quantity of rainfall occurring in a period of time. For agricultural research and public assistance concerned with failure of crops, a specific total of rainfall was typically used as an indicator. The amounts used were selected either from actual experimental knowledge of crop water requirements, or from general experience of administrators about the relationship between rainfall amounts and regions with lower yields and limited crop options. Older studies (pre-1970) also occurred at time when there was less knowledge on crop growth and water requirements, another reason to use annual rainfall totals. For researchers linking more with questions about economic development and investment, levels of tolerable risk of crop failure became one guide in the search for rainfall totals and rainfall patterns that could adversely affect returns to investment or bring destitution.

In colonial Africa, a model of agrarian transition was already in place that hypothesised a shift between subsistence, transitional and commercial farmers, which also shaped a very influential paper that reached into the Royal Society. Manning (1956) made probability analyses of annual rainfall using the normal probability distribution to study the chance that farmers failed to get the seasonal rainfall required for certain crops. He considered that larger farmers would have assets which could tide them across bad years, which small subsistence farmers would not. The levels of risk adaptation he identified for different farmers, to rainfall received 95%, 90% and 75% of the time, for subsistence, 'emergent' (moving into commodity farming) and commercial large farmers respectively - still influence many statistical studies of rainfall. As will be seen, the 10% risk has also become a common risk assessment level in water resources planning (see Chapter 7).

A second stream was to look at the length of a 'growing season' at different levels of risk and reliability, as a tool to help the general design of new farming systems. In West Africa, Cocheme and Franquin (1967) began identifying the growing season and the concept of 'moisture availability periods' (MAI) by comparing evapotranspiration with average rainfall, although it could also be compared with probabilities rainfall such as manning (1946 discussed). In India, such work also began in the 1960's (George and Krishnan, 1969) but, took on different conventions, as will be seen in Chapter 3. The IMD developed a variant of the MAI that was very much their own creation. Biswas and Sarkar (1978) took the concept developed by Cocheme and Franquin (1967) to compare the ratio of precipitation to potential evapotranspiration, then adopted some of the ideas of Hargreaves (1967), who used a rainfall probability of 75% probability to calculate the time period and rainfall amount when this ratio was above 0.3 (when the soil conditions were considered to make plants wilt and die). However, they also performed the calculations on weekly periods, and also calculated periods when the ratio was above 0.7 when there should be no stress on crops (and when higher demands from growing crops could be met). They published a range of rainfall probabilities from 10%....90% (from the gamma function) so that planners could choose their risk levels. For climatic mapping, for their own mapping purposes, 'assured rainfall' was that received 50% of the time, but they also used 30% and 70% levels.

A third stream was the analysis of typical and aberrant weather conditions within a season: this helped in both forecasting, and in design of crop strategies. These emerged rapidly from regional and international contact from the late 1950s, as both climatological and agronomic knowledge grew (Glover and Robinson, 1953; Lineham, 1972; Raman, 1974) It is also no surprise that such studies emerged more commonly where there was good interaction between meteorological and agricultural research organisations (as in

India, and in several colonial African states). Nevertheless, these techniques said little about the vagaries of actual production year-to-year for the small farmer.

The question of how to study risk in physical water availability remains an area of debate. On the one hand, the older work of Manning (1956) has been superseded by debates that argue that even small farmers can make cropping choices that face higher levels of risk if they have relevant support and social networks (or can grab the water), and that it is runs of years that create more difficult problems. However, Manning's 95% criteria still has some value. It indicates a core element of reliability of water, in quantity and timing, as well as risk in other periods. This is information and understanding that subsistence farmers may still work with for their general farming strategy, even if they take risks in growing additional crops. In areas without great food security or water security, where farmers must still rely on own production due to low purchasing power or lack of food for sale, this knowledge of more secure production periods and related crops remains important. This will be seen in section 7.6.

Jodha (1991) argued that, for agricultural drought, it was important to distinguish research and development related to farmers' strategies, separate and additional to research and development on the 'production environment', also to recognize that there were also very different kinds of farmers suffering drought and living in drought-prone areas. However, while economists and farming systems analysts urged study of factors and environmental risks that restricted new investments in agriculture, and helped understanding of farmer decision-making, few meteorological scientists had taken up this challenge by the time of the study reported in Chapter 3.

Beyond data collection and analysis, the other responses of science and technology were to develop practical artefacts and organise responses to combat drought. These were:

- droughtproofing measures – to hold water or mobilise water – typically in wells, dams and diversions for irrigation and watershed management strategies;

- drought mitigation strategies – water allocation and access strategies designed to lessen the impact on people, and changes in farming practices;
- emergency drought relief

However it was irrigation that became targeted as the best panacea' and best 'droughtproofing tool' – seen as vital to stabilise production, support niche crops appropriate to these regions, reduce inter-regional economic contrasts, and distribute new benefits to poor farmers. Tools for planning water development for irrigation are the main focus of chapters 4-7.

2.6 GROUNDWATER DROUGHT

Groundwater drought, shaped by lack of rainfall that reduces recharge, manifests itself through reduction in the yield of an aquifer overall and in individual wells – through the early falling of water levels and yield, that limit the period available for pumping and number of crop seasons, and reduced crop area within a season. Growing dependencies on groundwater to provide water during a drought period drive further over-extraction. Olsen (1987) wrote unequivocally that it was 'man-made drought' that had emerged in Andhra Pradesh through the huge expansion in well numbers and volumes extracted.

The development of speciality knowledge and specialty agencies to mobilise groundwater in a droughtprone area has had a very different dynamic from that for agriculture. Much of the basic physics of groundwater movement and flows to wells were known by the early part of the twentieth century, and the basic importance of geology for mineral wealth as well as water made geology another early scientific specialty of empire. However, it was the rapid emergence of new drilling technologies and pumps in the 1950's, and the identification of well development as part of

development strategies in many areas, that shaped agencies for groundwater development.

Generic frameworks for groundwater behaviour have been exchanged across the world, both for water movement in geological formations, and also the design of access technologies like open wells, tubewells, springs and seepage points. Actual data on water levels and water yields have become standard items of monitoring. However, other intrinsic behaviour – groundwater movement, well behaviour and water balance and safe yield of aquifers - have all largely relied on modelling with this data. Development programmes have often worked with model schemes for costs and returns and risks to farmers, which have rarely been tested in reality (Vishwanathan, 1983; ARDC, 1980).

Agencies emerged for technology dissemination at the same time or even before agencies or departmental units were in place to plan the use of groundwater – creating problems of consistency and congruency in actor networks that have never gone away. While groundwater development programmes were often assisted by foreign funding, these projects did not at first bring the scientific tools and ideas for regional planning of groundwater. These instead had to be 'homegrown', for use in local agencies often without funding for research except where externally funded. Studies on potential for groundwater development in a drought-prone region have thus first and foremost been related to changes in levels and to numbers of extraction devices, that can be equated with 'safe yield' under normal and drought conditions. While the early efforts to develop models were respected because they nevertheless tried to assist urgent programme needs (ARDC, 1978a and b, 1980), the lack of real change in recent models has left them subject to extensive criticism (Moench, 1992). These routines underpinning the 'science' of groundwater drought are analysed further in Chapters 4 and 5.

For studying the changes and misfits around agency and cognition, I draw on several writers who have tried to open up the social dimensions behind increasing groundwater drought and the nature of scarcity. Burke and Moench (2000) have charted the stages of evolution of groundwater, from (i) popularisation of technologies, (ii) rise of new groundwater-based agrarian economies (iii) early signs of groundwater overdraft (iv) decline of groundwater availability to levels where it has effects on the economy and quality of life. Each stage has different characteristics locally and policy requirements regionally

In the 1980s, as drilling technology was expanding, Dhawan (1982) highlighted the need to understand the economics of tubewells, because of the unique dualism starting up between traditional and modern methods of groundwater irrigation in India. There were important questions about how the state could regulate groundwater to prevent its exploitation that were still unanswered as its expansion began. He also noted that tubewells were largely an assembly task, where there were a variety of methods and materials that could be studied in relation to the development of tubewell/borewell proper, the pumpset, the water distribution and power source. These shaped their costs and also their dissemination, and the assemblage dimension meant that little real science might be needed in their installation and use.

Chandrakanth et Arun (1997) wrote about the changing levels and scope of analysis that could be used to separate problems of drought impact and scarcity for groundwater. Early studies tended to focus on the degree and type of well interference and groundwater exploitation, often with particular focus on the dry and drought-prone regions. Later studies could study investments (physical and institutional) in coping strategies, as a reflection of the economic scarcity understood by farmers. In this respect, Chandrakanth and Arun (1997) found that additional costs like drip were rarely taken up by farmers unless economic scarcity was really severe. They also tried to look

inside relations between numbers of wells working in a village and the volume of groundwater available in the aquifer, as a means to understand real interactions between wells (and other water bodies locally) and thus what different technical and social options might really be of relevance. This approach is followed in Chapter 5. Such 'scarcity-related' study required much local interaction and knowledge which most techno-scientific agencies would or could not undertake, leaving most 'scientific' studies of groundwater scarcity stuck in the first level analysis of well density and interference, or more abstract modelling.

Shah (1990) argued that as over-exploitation continues, groundwater management regimes might go two ways: in the first, the groundwater balance is disrupted and the farming system falls to a new (lower) equilibrium level of production and income. Alternatively some rules may be accepted, and that some organisational forms could be better in helping these 'self-correcting mechanisms' to emerge. Changing legislation to allow flexible and often multi-purpose organisations for managing borewells or borewell clusters, and support for such organisations has been a focus of public action in the 1990s.

Kolavalli and Atheeq (1995) tried to define generic behaviour of wells that indicated water scarcity, with particular reference to hardrock aquifers. These included: water quality problems; declining groundwater levels, both as lower levels occurring earlier in a season, and falling to qualitatively lower levels; open dug wells drying up; borewell depths increasing; borewell yields decreasing; and borewells falling dry. As chapters 4 and 5 show, these could all be monitored locally in villages, but responsible agencies have hardly changed their analytical procedures to develop this new understanding.

Dubash (2002) highlighted how the private market has proved much more influential and successful than public agencies in dissemination of well and pump technology, and

that markets – or at least locally shaped exchange groundwater mechanisms – may be eventually more influential in groundwater management than any public initiative to register and legislate well development and control groundwater access. Moench (1991) and Knecht and Vincent (2001) highlighted the relevance of studying the social interaction that could be promoted around the different technologies involved in mobilising groundwater, where electricity may give more options for collective action than water exchange.

2.7 SURFACE WATER DROUGHT

Surface water drought is visible as the effects of low or intermittent flows, dry rivers and reduced water storage. Models of throughflow and runoff have been debated since the 1930s, but basic scientific routines and statistical analysis to study patterns in river flow have been around since the early 1900s. Given the importance of water for domestic use and irrigation, and simpler technology historically and locally available, many countries have had longstanding ordinances and laws defining surface water rights (unlike groundwater), often with clear courts of legal redress. However, the critical importance of irrigation to development has often put responsibilities in monitoring and planning inside agencies for irrigation or agriculture. This often stifled research on hydrological processes, except as they related to quantitative availability of water, and indeed made research a poor relation to the development of norms that helped construction and operational needs. The transforming point in which a water agency or river agency can assert itself over other state departments is often a critical one in the cognitive frameworks for water management in droughtprone areas and scarcity conditions, and this is a focus of interest in Chapter 7.

Monitoring of surface water drought perhaps has even more problems than groundwater and rainfall, because of the costs in developing measurement points and difficulties in designing hydrometric networks to study and monitor runoff and its relations with meteorological conditions. Despite the basic importance of surface water in many areas, debates about structural scarcity - how definition of rights and design agencies lead to social exclusion of some groups - and physical scarcity where water is overallocated and extraction improperly controlled - are relatively recent (Waller, 1994; Bolding, 1999).

Risk questions are also critical to these water resource planners and designers. Rees (2002) argues they must be treated as social as well as scientific concepts. She emphasised that while risk assessment needed to be based in good physical science and technology, the wider social forces shaping water management also need understanding. Economic, political and ecological sources of uncertainty can have major implications for water allocation and people's access, beyond hydrological uncertainty. The analysis of river flows to make plans for abstraction is more complex and challenging because of the variability of flow in space and time, and the impact of offtakes in one point on another. The costs and difficulties of monitoring rivers in many developing countries, and complexity to synthesise and analysis relationships across river networks, meant that many countries developed proxy indicators of runoff, typically relating runoff to rainfall. The use of such formulae is discussed in Chapter 7. As more data is available, flow frequency and flow duration curves enable comparison of yield with and without storage of different levels of cost. Typically, levels of water allocation are allowed to increase in relation to probabilities of surface water availability, as more water is stored: however the analysis can shift between actual flows and total annual water received. As Chapter 7 discusses, allocation of flows received 10% of the time has been used as a planning norm in Rhodesia/Zimbabwe: it

has been applied to flows when there is no storage and the annual water yields where there is reasonable levels of storage. Higher levels of allocation can come with greater storage and over-year storage.

The planning for use of river water involves understanding of the behaviour of flows in themselves, but also the economic impacts of failure of flows and social impacts of conflict between users over water along a river system. However, the scope of impact and nature of risks investigated have changed over time. While risks of low flows were first assessed against irrigation and domestic security, they have now expanded into requirements for more ecological security, to give minimum flows for aquatic life and against pollution (Falkenmark, 2003). Currently, the concern for economic productivity from water has meant new debates about how to maximise the efficiency of water use against equity of water access that minimises conflict (Rees, 2002).

To study these points, I draw on the work of Hladny and Buchtele (1989), who emphasised two critical areas in hydrological analysis to support information to plan and act against surface water drought.

- design values for protective facilities and measures – not only physical measures like construction of dams, but plans and legislative steps for water management in a drought: this is the main field addressed in the latter part of Chapter 7;
- warning and forecasting tools.

I also use a rather standard framework for the work of a hydrologist, in order to later criticise it in Chapter 7. Kohler, (1957, p.1) noted that.... 'In the broadest sense' hydrology treats the occurrence of water on the earth, the description of the earth with respect to water and the relation of water to life on the earth'... He proposed that the problems confronting the hydrologist could be segregated into two categories: those pertaining to 'planning and design', and those dealing with 'operation'. Kohler's conceptualisation is shown in Table 2.2

Looking at this framework 45 years later, we still see such tasks dominating, but I argue that tasks must widen. The issue of the relationship of water to 'life on earth' should highlight the question of 'which social groups' and with 'what social and economic development concerns' in mind is data collection designed? Equally, the tools in use for planning and operation also have to consider the options of debate and enforcement of institutions for managing surface water, both in the planning and operation dimensions. This issue is taken up further in Chapter 7.

Table 2.2. Problems confronting the hydrologist (after Kohler, 1957)

Planning and design problems	Operational problems
<ul style="list-style-type: none"> • Spillway capacity (for reservoirs, stock ponds etc) • Levee design and channel improvement • Storm drainage • Power potential estimates • Available water supply (with or without storage) • Safe yield of groundwater, well-spacing etc • Flood damage frequencies and determination of flood risk • Estimates of consumptive use and reservoir evaporation 	<p>Short range forecasts</p> <ul style="list-style-type: none"> • Operation of dams • Flood forecasting, also for evacuation and withdrawal of movable property • Low-flow navigation planning • Scheduling diversion and distribution of irrigation water • Scheduling power production • Planning construction in or near stream <p>Seasonal and annual forecasts</p> <ul style="list-style-type: none"> • Basis of long-range flood control operations and flood containment • Agricultural planning in irrigated areas • Basis of power operation schedules • Planning for municipal supply • Long-range navigation planning

I would also highlight the concern for water allocation and monitoring of water access, missing in the above, but now central to many water planning dilemmas. I also believe that understanding of operational problems must (re)shape planning and design activities: indeed many failures in irrigation systems are a consequence of their designers giving insufficient thought to the practical operation of systems.

Waller (1994) used a political analysis to study how expertise and elite groups held control over water allocation and management. He explained how it took the crisis of a six-year drought in California to expose the control over policy agendas and control over policy reforms by an elite set of interests and expert systems. Only after new claims from urban legislators and new lobbying groups, and the mass media attacked poor water management, were reforms pushed through. Only then could a strong technical image and power alliance between water agencies and powerful farmers be confronted to get new water conservation programmes. This framework also informs the study of surface water drought in Chapter 7.

There are calls from different researchers to develop a more holistic view, for capabilities to study the dynamics of drought and scarcity together - to understand 'water cycle drought' (Bandhopadyay, 1987) and for the reconstruction of water resource management systems that have institutions and agencies capable to manage water in a sustainable, equitable and compassionate ecological framework. Several frameworks for water management – integrated water resources management, river basin organisations – have been actively debated (Abu-Zeid and Biswas, 1996; Hufschmidt and Tejuwani, 1993; Wessel et al., 1999). I think this is also an admirable objective – but I also recognise that in the context of many states of development, these idealised new frameworks are difficult to render feasible nor always desirable (see also Wester et al, 2003). Rather I hope that the findings in this thesis show the importance to understand the interacting politics of knowledge and agency related to drought and scarcity, in thinking how to bring new and more inclusive water management.

2.8 CONCLUSIONS

This chapter has built a conceptual framework to study the cognitive history of drought and scarcity, as shown through public agency in drought-prone areas. Choices in the framing of problems, and methods of data collection and analysis, and their use in technological design, have powerful effects on how allocation, negotiation and transformation of water management can take place. Wicked social dilemmas are embedded in the planning and monitoring of water resources. Science and technology are socially constructed (Rose and Rose, 1976) and transformation in the scope for analysis will need change in analytical frameworks and tools to meet the needs of different groups. The studies that follow trace what happens if, in the name of economic development, scientists, engineers and instrumental actors fail to make resource evaluations or choose technologies consistent with the environment and public they are supposed to serve.

INTERMEZZO 1

PUBLIC AGENCY IN THE DROUGHTPRONE AREAS OF INDIA

The purpose of this intermezzo is to outline both the orientation and form of public agencies and programmes that developed in India, and shaped water availability in the droughtprone areas of India, as described in the next three chapters. A second intermezzo precedes Chapters 7 and 8 on Yemen and Zimbabwe, which highlights key differences of these states in their public agencies working in droughtprone and scarcity-affected areas.

Rural development in India has been pursued through a series of Five Year Plans (FYP). The 1st FYP began in 1951/2: the 10th FYP (2002-2007) was underway as this study was written. During these plans, a number of special programmes have been launched by Central Government and locally implemented by State governments. Central programmes are not legally binding on the states, but operate through financial influence, as state governments have limited prospects to raise their own funds. These programmes have not only influenced water resource development. The third FYP was generally considered the start of policy formation on natural resource development, to be developed on 'scientific lines'. Disastrous food shortages, combined with extensive American influence promoting programmes and agencies for technology dissemination (with both subsidies and credit packages), also helped to spearhead many irrigation development initiatives that were at their zenith during the 4-6th FYP. The year 1971, and the period 1969-1975 (fourth FYP) was something of a watershed for the creation of a number of special water monitoring units newly set up, or carved out of older bureaucracies, who are prominent in this study. These helped monitor resources and plan water extraction in relation to the new development programmes.

Apart from changing content, the scope of water programmes was also shaped by administrative discourses. They include shifts in attitudes between elected or appointed

officers in programme administration (in villages or specialist agencies), towards credit-based rather than pure welfare assistance, and promotion of individual rather than communal assets. The emphasis on 'Community Development' or 'Panchayat' organisations emphasised by early plans (influenced by the personal philosophy of Nehru) shifted towards specific organisations for rural development during the Third FYP (1961/66) – creating the District Rural Development Agency (DRDA) - separate from local government. However, since the 7th FYP there has been a re-emphasis back on using community organisations, but with elected representatives. Liberalisation and financial reforms from the 1990s, and development discourses promoting local institutions, have also focused attention on local water user and livelihood associations and district-based monitoring of resources (see Chapter 6).

A number of thematic policy concerns, or framing discourses, are central in the next three chapters. These include major debate on, and programmes for:

- a) **rural development and poverty alleviation.** Crucial to droughtprone India generally, and the next three case study chapters, is the **Drought Prone Area Programme (DPAP)**, launched during the 4th FYP and still in existence in 2000, which emphasised creation of community assets that helped create resilience against drought. The DPAP has had an extremely important influence on the mobilisation of surface water and groundwater for irrigation. Critical cognitive elements for this programme were: the areas considered relevant for programme assistance, the availability of water resources that could be mobilised under the programme, and the water sources and technologies to focus on, examined in Chapters 3 and 4. Its funds were released for small irrigation systems in areas without widespread availability of large irrigation systems. Under this programme, normal criteria of hydrological suitability¹ were often

¹ Irrigation dams funded under this programme are permitted to be constructed at 50% dependability rather than 75% (i.e. they fail to fill 50% time). Equally borewells are allowed funding that have lower yields.

suspended, so that small water supplies could nevertheless be developed for poor and marginal farmers in difficult areas. **The Integrated Rural Development Programme** was launched in the 6th FYP for employment generation and household asset creation. It essentially assisted individual farmers through subsidies and loans, and did support programmes giving small farmers access to pump technology.

- b) **Special programmes for scheduled castes and tribes (SCSTC)**, which have been used to fund irrigation development to these socially excluded groups. SCSTC schemes often had to mobilize projects in areas of very poor water resources. In later programmes, greater emphasis was given to employment generation, in which the construction and provision of irrigation works declined. These programmes operated from District-level Societies that also worked closely with the DRDA;
- c) **Drought Relief Funds** released by Central and State funds at times of 'scarcity'. While these often involved employment generation (sometimes constructing irrigation works), they were also used to cover emergency water supply needs. New community wells and borewells could get dug when existing sources failed, or small dams be constructed or renovated. Drought relief work was usually under special sanction of government officials, and could be outside norms present in other programmes.

India also has a long tradition of public agencies involved in water monitoring and development. Some had colonial origins, and echoed developments in the United Kingdom. For this study, several of these older institutions are particularly important. The oldest was the Geological Survey of India, set up in 1851. However, although this undertook some survey work on groundwater from the 1960's, a specific Central Groundwater Board (CGWB) was only carved out from the GSI in 1971.

Percolation tanks to support aquifer recharge and associated well development are also common. For many years, the DPAP also hosted special work on 'Watershed Management', following on from earlier soil conservation programmes.

The Government of India proposed a Groundwater (Control and Regulation) Bill in 1970, as the scale of groundwater development under tubewells began to become apparent. State Groundwater Departments also date from this time, although they often took time to become established. With the Agricultural Refinance and Development Corporation (ARDC), the CGWB set up the Central Groundwater Estimation Committee in 1985, with guidelines for the estimation of groundwater draft, and State Estimation Committees followed. As Chapters 5 and 6 will show, the experience of the state groundwater departments has been a troublesome one. Their build-up of identity and respected scientific performance has been poorer than other agencies with older and more independent scientific credentials. I describe these state agencies as specialty agencies with quite low cognitive and social institutionalisation, which has often made them uncertain partners in development initiatives, while also very dependent on external programmes for funds and scientific identity.

A second was the India Meteorological Department (IMD) established in 1875. This was variously located at Calcutta, Simla and Poona before being finally located in New Delhi. It developed an Agricultural Meteorology Division (AMD) in 1971, based at Poona, which was my base for the study documented in Chapter 3. I characterise the IMD as a specialty agency with both strong cognitive and social institutionalisation, with a well-established bureaucracy which allowed it to run its own operational tasks as well as its research areas. The Agricultural Meteorology Division, still relatively young at the time of that study, could be thought of as one of IMD's Research Areas at that time, but one still quite well-structured into the strong cognitive and social institutionalisation of the overall agency. Well-established and accepted observation and calculation methods of IMD simply spread into the new divisions and programmes of AMD.

A third institution with colonial origins stems from the Imperial Council for Agricultural Research, renamed the Indian Council for Agricultural Research after

Independence. A focus on the problems of dryland farming began as early as 1923, and in the period 1933-43 five research stations became operational to develop dryland farming practices for their area. Of particular relevance to this study is the station at Sholapur. However, in 1966 ICAR launched the 'All India Coordinated research project on Dryland research based on 27 stations, to be located in 'typical' agro-climatic zones. I would also characterise this programme as a 'research area', but one strongly linked with the norms of the Specialty agency it belonged with, and also showing strong cognitive and social institutionalisation.

The final institutions with colonial roots were certain Universities and Agricultural Colleges. The (Bombay) State Department of Agriculture emerged in 1877, and a College of Science was created at Poona in 1879, after a noted Indian agriculturist lobbied the British government. This was renamed the College of Agriculture in 1907 and became one of the five first Universities to give an Agricultural degree. This college was later absorbed into the Maharashtra Agricultural University network in 1968. At the time of study discussed in Chapter 3, Poona was still the site of the Vice Chancellors office, although the main campus was identified as Rahuri in Ahmednagar. As will be shown in the next chapter, there have been direct funding relationships at times between ICAR, the Agricultural Meteorology Division, and the Poona campus. These allowed good links and contacts to be formed, backing up key preferences to combine practical observational data linking statistical and crop biological phenomena – but excluded other data.

However, both the Central and State governments developed agencies as necessary to suit the wider needs of planning and development. In fact, India's policies on science and technology development, under a Ministry, were also quite distinctive. This Ministry looked quite systematically at which technologies it has wanted to promote and thought about agency structures for their dissemination and uptake: well technology is a particular focus for Chapter 4. However, credit sources for technology uptake have also been a

special concern, given historical dependencies on non-institutional loans (money lenders and traders) and persistence of indebtedness.

Village co-operative societies began as early as 1904, but in 1961 formal institutional credit still provided only 1% of actual requirements. State land development banks, which federated Primary Agricultural Credit Societies for short term loans, emerged 1920-1940 in some states. However, these credit sources did not emerge in the areas studied until after the new states were created. In 1969, nationalisation of banks meant that commercial banks could also become involved in giving loans. Finally some special regional banks developed from a combination of central state and commercial bank funds. However, a serious problem throughout has been big farmer bias and the lack of lending to small and marginal farmers.

Given the Central government's insistence in a credit component in many of its promoted plans (alongside a subsidy element for small farmers), a special corporation was set up in the mid 1960s - the Agricultural Refinance and Development Corporation (ARDC) with funds from the World bank and bilateral donors to 'refinance' these local loans and related agencies. This was replaced by the National Bank for Agricultural and Rural development (NABARD) in 1981, which gained responsibility for policy towards central financial support for agriculture. Minor irrigation became a specific and important part of their work. Both ARDC and NABARD had important powers for the scrutiny of accounts and investigation of procedures of banks and other corporations set up with public and private capital to spearhead technology dissemination. Both became heavily involved in setting technical norms for clearance of borewell and pump developments for bank funding, not otherwise available from other research, monitoring and technical agencies emerging at this time. I also describe ARDC and NABARD as having strong social institutionalisation. However, its technical staff often faced problems in building links into other scientific and technological agencies, precisely because they were not seen

to come from a more specific scientific and engineering specialty background, and powers of financial scrutiny and technical scrutiny did not always favour good personal relations.

The structure of a corporation also emerged to deal with these special technology dissemination needs - capable to receive public and private funds, develop new technical norms, liaise with banks over funding, and act speedily among the numerous departments and groups operating at local level. One corporation important to this study is the Andhra Pradesh State Irrigation Development Corporation (APSIDC), set up for implementing surface and groundwater 'lift' schemes, in 1974 (although branches only emerged in the droughtprone area in 1981). Other corporations of this kind included the Andhra Pradesh State Agro-Industries Corporation (APSAIC), which had a special division dealing with agricultural pumpsets. A third was the Andhra Pradesh State Cooperative Rural Irrigation Corporation (APSCRIC), who became involved in installing 'dug-cum-borewells' - a technology for deepening open wells. These corporations were specialty agencies - or ventures really - set up by public and private funds and very shaped by political forces. As will be seen, their operating environment actually gave them little time for research, and relations with more research-based and science-based agencies were problematic for these 'implementation-biased' agencies. Their technical norms in use often emerged in a rather ad hoc and pragmatic way, and they were influenced as much by banks and ARDC/NABARD as the Groundwater Department. While often led at first by charismatic directors, later financial problems and technological underperformance limited their cognitive transformation, even when linked to external development assistance, as discussed in Chapter 5.

Beyond these 'specialty' agencies in scientific and technical performance, lay the general rural development agencies and district committees involved in implementing state plans and applying, coordinating and disbursing subsidies, and local government authority overseeing them. The most significant of these for this study was the District

Rural Development Agency, created from 1985. Essentially a planning agency disbursing funds to other implementing agencies, they nevertheless had some technical staff from various ministries and departments attached to them. Mainly, however, they were administrative and financial staff. Here the study will show other special problems, as accepted technical norms and research interests sometimes got subverted by administrative and financial interests. Another significant agency was the Scheduled Caste Finance Corporation that allocated funds to a range of implementing agencies (including APSIDC, and the Irrigation Department). At district level resources were managed through District Service Cooperative Societies for Scheduled Castes, Backward Classes and scheduled Tribes (SCSTC). They could contribute additional subsidies as 'margin money' – a kind of hypothetical long-term loan. These subsidies provided important 'top-up' funding for special community programmes. Coordinating these agencies and running regular meetings on planning and action was the District Collector responsible for law and order.

Beyond this complex mix of agencies acting in the public domain, lie also many NGOs active in the civil/informal sphere, whose work will be discussed more in Chapters 5. However, one last scientific influence and interest to mention is international research, and also development agencies. ICRISAT, the International Centre for Research in the Semi-Arid Tropics based at Hyderabad, had a special interest in drought-prone areas and its Agricultural Meteorology and Farming Systems divisions sought special links with IMD and ICAR. International agencies like the World Bank and The Ford Foundation, and also some bilateral programmes, sometimes funded special staff in to assist new agencies

Alongside this complex web of formal public agency for programme implementation and resource management typical of a developmental and democratic state, was an equally complex structure of legal institutions for water management. However, a system of rights with disputes handled in civil court has not been able to spawn new state-level regulations

for groundwater use (although many Model bills exist, see Knecht and Vincent, 2001). Some authors see this as another domain that India is 'leaving to the market', although Dubash (2002) argues that locally-shaped exchange practices can yet emerge to combat the growing control of a rural elite over groundwater resources. This lack of established regulation and institutions across all areas of water is one distinctive difference between India and the other case studies discussed in Intermezzo 2, although all countries do show common struggles to access water that are often shaped and brokered by new interventions.

The scope of the states to follow through on central plan guidelines has been shaped by their creation as well as political configuration. The state of Andhra Pradesh was recognised in 1956: the state of Maharashtra was recognised in 1960, when the old Bombay state was split up into Maharashtra and Gujarat. Maharashtra state used the annual isohyet of 750mm, together with an incidence of irrigated area under 15% to demarcate its DPA. The Andhra Pradesh (AP) government used an annual isohyet of less than 750mm and a criteria of less than 20% of local administrative units were irrigated, and an annual isohyet in the range of 750-1125mm if a block had less than 15% of the area irrigated. The AP conditions were thus more favourable to areas actually being declared droughtprone. After a review in 1982 of the DPAP by a Central Taskforce, AP was forced to axe 15 blocks from its DPA because of actual area irrigated. The Taskforce also insisted that new blocks could only be added if the irrigated area was less than 20% or 15% – but this still left Andhra Pradesh disbursing money into areas with more irrigation than in other states.

There are historical differences in the political dynamics and priorities between Andhra Pradesh and Maharashtra states, which have shaped the evolution of institutions and continuity and breadth of data sets. These differences were underscored by radically different political histories during the 1990s: different grass root politics,

different styles of the Chief Minister and very different options for international donor assistance. Maharashtra, with its longer history of cooperative movements, welfare altruism, and political activism remained a hotbed of NGO and other civil society activism underneath more fundamentalist Hindu politics, who continued to drive many new paradigms for building resilience in the drought-prone areas.

Andhra Pradesh meanwhile reinvented itself in the 1990s with both populist and neo-liberal rhetoric on 'good governance' that attracted a lot of donor attention – although on the ground it had many fewer civil society organisations and radical programmes than Maharashtra. In Andhra Pradesh, water was given a unique profile by the Chief Minister himself, Chandrababu Naidu. He put a special focus onto water conservation with his 'Neeru Meeru' programme, which became pushed through newspaper supplements, television coverage and video-conferencing with local officials, some of which was even reported on public television.

What I hope to show in the next three chapters is that while drought has been of critical concern in India, the actual contribution to critical cognitive and technical norms to help sustainable development in DPAs has been rather limited, and scientific networking in particular has been very poor. Where specialty agencies had strong cognitive and social institutionalisation, they tended rather to stay within themselves and coexist with other agencies in an easy but rather detached way. Thus elite scientists coexisted with the representatives of informal civil society quite well, but rarely absorbed from them any radically new cognitive frameworks or technical ideas on drought and drought impact/mitigation. This is visible in the chapters looking at studies in agricultural drought and agricultural meteorology. When agencies were neither strongly developed as specialties nor strongly institutionalised – as will be seen in groundwater development – there was a much more complex interaction and influence between agencies, in what were technoeconomic rather than technoscientific networks. They also found difficulties in

stopping inappropriate and corrupt activities, that often emerged because of the pressures and opportunities in these networks. The main users of the information generated were usually other agencies involved in development assistance or technology dissemination. Farmers interacted with agencies to take up their financial assistance, but often were not finding them that useful for their operational decisions. Recognising this political economy of public agency and how they broker, control and achieve programme tasks – and how it utilises or brings relevant science and technology or not - has been one learning curve in my own cognitive history in understanding development options in droughtprone areas.

CHAPTER 3

AGRICULTURAL DROUGHT AND AGROMETEOROLOGICAL RESEARCH IN MAHARASHTRA STATE

If there is one single natural factor that can undo the progress of agriculture, it is weather. Farmers have always been weatherwise, but it was the Royal Commission on Agriculture (1928) which was responsible for introducing meteorological thinking in the science of agriculture in India. The Royal Commission had ...stated that there were two directions in which scientists interested in agriculture should undertake investigations of meteorological nature. The first was statistical and the second biological...Progress in the field of agricultural meteorology in the country has been mostly in setting up of observatories in agricultural farms. Meteorological research in close association with agriculture has been limited. Ministry of Agriculture 1971 Preface

A scientific study of the problem of Growth and Instability in Indian Agriculture is possible only if comparable agricultural and meteorological data are available for a sufficiently long period. Sen 1969, p. 827

3.1 Introduction

This chapter reviews the application of the science of agrometeorology into studying agricultural drought risks for development planning in the droughtprone area of Maharashtra (DPAM) state in 1979 - the end of the Fifth FYP period - and the agencies involved in this scientific enterprise to chart an area. Thus this chapter demonstrates at least two of the relationships of science supposedly contributing to technology outlined by Brooks (1994). These include being a source of tools and techniques for more efficient engineering design (in this case for farming systems), and widening a knowledge based that enables more efficient strategies of applied research, development and refinements of technologies. The objective of this chapter is not only to show the critical cognitive and technical norms put in place, but also the gaps that remained in the generation of tools and ideas useful for the development agencies and farmers struggling in the DPAM. Contributing to, and being part of, development agency in the wider sense was left outside the work of these scientific ventures. By detailed reporting of my own and others' work, I hope to show the minutiae and levels of abstraction that can also absorb and overtake the unwary scientist.

For understanding the cognitive and technical norms used in recognising agricultural drought in these earlier times of development planning in drought-prone areas, this chapter looks critically at the work of the Indian Meteorological Department (IMD) and the Indian Council of Agricultural Research (ICAR). It looks at both the models they used and knowledge partnerships they worked in, at the time when the DPAP programme had been running for 8-9 years. A serious drought in Maharashtra, which ran for almost 3 years 1970-1973 had also brought strong state government attention into the predicament of farmers in the DPAM, building on earlier 'Scarcity Commissions' (Government of Maharashtra 1973, 1960). This chapter also documents studies I undertook on drought working alongside IMD staff, both to extend understanding and also find simple models and criteria for various needs in local development programmes of that time. The chapter thus shows the first changes in my own cognitive understanding, in becoming aware of my own instrumentalist training and orientation.

The sections of the chapter are laid out in relation to the instrumentalist view I – and others – had at this time. After a review of the institutions under study, there follows two quantitative sections that study climatic data in different ways, based both on characteristics that scientists thought might be influential on production, but also as shaped by the nature of data available. Each section looks at what agencies were doing, and the additional studies I tried to undertake. Section 3.3 documents the studies of precipitation considered relevant to crop potential (and thus a focus of action for droughtproofing). The studies developed by IMD and ICAR focused around rainfall and 'aberrant rainfall' conditions for crop planning, while the analyses I developed tried to bring in more of a livelihood focus, particularly through dryspell analysis and study of runs of poor years. These sections show that, whilst IMD and ICAR could have worked more together on ideal crop planning needs, they did not at that time

relate to wider agricultural economics and farming systems research. The focus then also was still overwhelmingly on 'kharif' weather in the monsoon with less attention to post-monsoon 'rabi' conditions. Section 3.4 examines water balance studies around rainfall-evapotranspiration-soil moisture models to show critical stress periods on crops (that could be used in planning and support for and with small farmers). The studies developed by IMD and ICAR only to some extent related weather crop evapotranspiration and crop yields, and did this through statistical analyses, while my analyses focused on crop-weather matrices and runs of good and bad years, and crop-weather models. Section 3.6 gives the conclusions, that really few criteria and models were available to assist many practical development needs. My work, while of personal interest to some, never got taken up or even reviewed in India. This was partly because of the social dynamics around the research, but also because I failed to understand about the networking necessary to bring changes in cognition and action.

This study was my first major overseas research grant, funded by the then Ministry of Overseas Development. Its objectives involved statistical analyses of rainfall and evapotranspiration patterns to understand more about critical dry spells for crop production in Maharashtra, and the wider links of dryspells to the monsoon circulation. I was drawn to the subject both by the growing literature on agricultural meteorology for agricultural planning, a specific interest in the linkages of drought, food and rural development, and also an interest in monsoon climatology. Like many at the time, I was interested to see if there were generic models that could be applied to the study of rainfall almost regardless of time and space. I was drawn to Maharashtra because it was the base for research in agricultural meteorology in India, it had excellent rainfall records (visible via the UK Meteorological Office), and the apparent lack of published studies from the state. I also knew it had a dryland production zone with an historic

core food scarcity zone, formally defined as a Drought Prone Area (DPA) in the Fourth FYP. Only once in the state did I start to learn and reflect on the wider social dimensions to planning for drought responses and structuring of drought research, primarily through field visits with NGOs, local agricultural research stations and colleges, and discussions with local Collectors at District level. My research permit and base was developed with the India Meteorological Department (IMD) at Poona, jointly with the Agricultural University of Maharashtra (then also still with its main offices in Poona). These links were facilitated by the academic networks that existed between British Universities and Vice Chancellors with active tropical research interests also concerned to get 'more young Brits interested and knowledgeable about India' (notably Reading University, which also was very active in agricultural meteorology at this time). Of the year's funding available, I spent an initial period reading on the monsoon, then four months in Maharashtra for consultations and data collection, returning to UK for the analysis and writing up of data collected. For this I developed my own computer programmes, either writing them myself or with help from a programming specialist. I had an extraordinary amount of support and cooperation from Indian scientific agencies at this time – even to the point of giving me the rainfall record of 22 selected stations on disk – a level of access to basic data I have never experienced since.

When I arrived in India, I of course found that a great deal of work had been done by IMD – but that this was published in their internal publications series (which was nevertheless critically reviewed), as befits a specialty with high cognitive and social institutionalisation. My plans then changed both to see where scientifically I might undertake new analysis and test hypotheses hitherto not done by IMD. However, almost at the same time, I became aware of the range of development planning needs in relation to drought response, which it seemed to me were not being researched. Thus, I also became interested in defining criteria and concepts and associative ideas for these

development concerns: later I also became interested to understand why these were not being investigated further in the plethora of agencies present. This chapter draws on the study published as Vincent (1981; 1980).

As the opening quote shows, cognition in agricultural meteorology in India has been ‘encouraged’ to develop in relation to very specific techniques of scientific analysis of weather – statistical models and biological data. Within IMD – as this study will also show – there was a commitment/intent also to rely only on their own observed data whose standards they monitored, or on the data of closely allied/trusted partners. This had streamlined their work very much into the analysis of rainfall only, or into the combined statistical analysis of rainfall, evapotranspiration and certain crop data. Statistical studies were only really seen as reliable if there were adequate data – at least 30 years, and IMD’s determination to work with ‘reliable’ data also makes their commitment to sustained observation understandable. Also distinctive in the opening quote was the reference to agriculture, rather than development per se. Finally, rarely is the word drought mentioned – rather it is scarcity or aberrant weather that is used in the scientific language. The framing cognitive discourses of these agencies did not address the wider development problems for the small farmer.

This section ends with a summary of the development needs where I felt agrometeorology should be trying to evolve contributions for development planning. As part of this study, I concluded that research into droughtproneness could respond to at least six administrative concerns:

i) environmental (especially meteorological) factors which influence the possibility to grow cash crops, in what were previously subsistence crop or pastoral areas;

- ii) distinction of drought-prone (also called scarcity-affected areas) from non- or less-affected areas, on which development plans or agricultural programmes could be concentrated;
- iii) signal criteria which alert authorities to impending or existing food scarcity conditions;
- iv) spatial differentiation within the general dryland farming areas, so that appropriate research methods and improved farming strategies may be designed;
- v) environmental and social factors which control the local traditional farming system, which should be considered in the design of improved farming strategies.
- vi) appropriate short-term relief measures.

I return to these administrative needs in the conclusions, to see what was supported by norms generated, to discuss what new insights were generated from my own analyses and to reflect why these cognitive gaps were present.

3.2 DROUGHT, PRODUCTION AND SCIENTIFIC AGENCY IN THE DPAM

3.2.1 Recognising instability and vulnerability

Maharashtra State came into existence in 1960, the same year as a scarcity study for the old Bombay state was published (Government of Maharashtra, 1960). At that time over 90% of the state was under dryland agriculture, and only 8% irrigated. Despite the recommendations of this 1969 scarcity study to expand irrigation (through large systems and well development) and practice soil and conservation works for better water retention, Maharashtra went on to face a further period of serious instability in food production. The level of production of 1960 – 7.7 million tonnes – actually never crossed 7 million tonnes again until 1974, and there was not a single year in that period

when either rabi or kharif crops were not adversely affected by the weather. Crop yields in the state regularly registered as lowest among all Indian states. The drought of 1965-68, followed rapidly by another serious drought 1970-1973, led to a further public enquiry on drought and scarcity (Government of Maharashtra, 1973), which called for more meteorological and agronomic research among other recommendations. The general emphasis was not just to identify drought risk, but to understand when and how to act in relation to the wider uncertainty and instability in food production. At this time, 25% of landholdings were less than one hectare (almost 45% under two hectares), while agricultural labourers largely without land were almost 30% of the agricultural labour force. Thus the problems of dryland farming output were also compounded by the difficulties for small and marginal farmers and agricultural labourers to survive across a drought period. At this time some two thirds of the state was under kharif crops (grown during the southwest monsoon) and only one-third under rabi crops. It was against these problems that the special assistance programmes of the 3rd and 4th FYP swung into being. Many development programmes were aimed at redesigning the cropping system, and to bring technologies that made it less vulnerable or diversified livelihood options. Drought relief – that ensured basic food supply and gave employment despite crop failure – also remained a critical and strategic political tool.

3.2.2 The involvement of scientific agency

Changes in science and technology raised new hopes for the droughtprone area and their dryland farming systems. The first of these changes was the evolution of High Yielding Varieties of crops, together with greater fertiliser production, and their integration with better water control for optimum yield. These new varieties were

usually also of shorter duration, thus changing options for catch- or sequence-cropping – especially if new dry seeding techniques were also tried. During the 1960s and especially the 1970s, there was a great leap in understanding about crop growth and equipment was developed for the monitoring of soil water movement, crop growth conditions and solar radiation. Computers arrived, making more sophisticated statistical analyses and models possible than before. Many aspirations and studies developed around these new technologies and analytical tools, including much use of replicated trials to study specific soils and crops. The ICAR Dryland Farming project began. While this did start comparisons of the cropping methods of local farmers with new ‘integrated techniques’ being evolved at research centres, early work still tended to comment that farmers for various reasons were not growing those crops most optimal to location. A set of interests was borne that has never gone away. Yield improvement, crop substitution, intercropping, sequence cropping, methods and dates of sowing, weed control, fertiliser use emerged as the first round of interests. By 1970, interests in water harvesting for supplemental irrigation and emergency measures for aberrant weather conditions were added – especially for delayed onset of the monsoon, long dry spells during the monsoon and early end of the monsoon (ICAR, 1979; Spratt and Chowdury, 1978).

However, these studies overlooked or ignored research results emerging from agricultural economists, geographers and field agronomists, that pleaded for more field-based micro-level studies of actual cropping practices (as opposed to cultivation methods). For example, it was known that farmers rarely grew any monocrop stands of any dryland crop, and that farmers traditionally intercropped as a means of risk spreading. These scientists argued along different lines - that it was important to understand crop association patterns of regional groups in the pursuit of better support measures and new crop combinations. By 1973, geographers had mapped the core

scarcity area of Maharashtra (Dikshit, 1973), to show typical associations of 1-5 crops grown by farmers. These crop regions had some contradictions with the crop regions that new agricultural research stations were seen to represent. (These new centres had been located in agro-ecological zones mapped from simple criteria using the ratio of average annual rainfall and evapotranspiration, as did Cocheme and Franquin (1967), which showed cropping periods for which new crops might be developed and recommended). Figure 3.1 shows my study of key crop associations and regions, indicating a crop zone of rabi cropping in the lee of hill areas hardly considered in crop research at the time.

The agricultural meteorology division (AMD) of IMD (henceforth AMD-IMD) was initiated in 1932, but was first largely involved in setting up observatories on agricultural farms focused on study of key agricultural crops (millet, sorghum, wheat, cotton and sugarcane). In 1945 an agricultural weather forecast service began on a regional basis. The AMD at IMD-Poona collated and analysed data from across India at that time, and did not run a special service for Maharashtra. However, Maharashtra certainly was one of the states for which AMD-IMD staff became interested to establish generic techniques that might be useful for mapping general water conditions for agriculture and aberrant rainfall conditions. In 1975, the Ministry of Agriculture recommended that all Agricultural Universities should have weather stations where a basic data set for rainfall and evapotranspiration could be recorded. In 1977 the IMD also installed its first lysimeters in which crops were grown (Sarker et al, 1976), so that water use and percolation across a growth cycle in relation to rainfall could be monitored. The links between IMD, and the scientists at both agricultural research stations of ICAR, and of regional colleges of the Agricultural University were thus quite close.



Fig 3.1 Crop regions of the DPAM in 1978 (compiled from District Agricultural Census data)

However, new technology did push new boundaries in scientific research. During the 1960's, dryland areas gained attention for their strategic importance in national food production – particularly for crops like pulses and groundnuts – and their potential to lessen food deficits (and thus food movement needs) with the production technology of the Green Revolution. At this time, a demand grew for techniques that could map potential constraints to crop options and yields. Thus scientists began to exchange ideas on agrometeorological mapping techniques, between regions and even continents, to search for more generic analytical tools. (At the same time also the search for new germplasm moved across countries, and weather mapping helped indicated specie niches and what might be exchanged.) Two lines of work relevant to this study were:

- spatial mapping of the boundaries of certain dryland farming areas by meteorological parameters (Biswas and Khambete, 1978; Mallick and Govindaswamy, 1963; Subrahmanyam and Subramaniam, 1965);
- onset of rains, water availability period etc, with a view to preparing statements on crop scheduling and crop conditions (George and Krishnan, 1969; Chowdury et al, 1978; Raman 1974; Ratnam, 1975).

Another group of scientists active regionally were those at CGIAR Centre of ICRISAT: although based in Hyderabad, the ICRISAT Agricultural Meteorology Division (ICRISAT-AMD) had taken up six rainfall sites across Maharashtra for their research into general analytical methodologies for rainfall in the semi-arid Tropics. However, it was the work of the farming system and agricultural economics group (ICRISAT-FS), under NS Jodha and Hans Binswanger that became more significant in portraying the riskiness of farming in the scarcity zone, and the problems created by runs of dry years. The ICRISAT-FS group were very active at this time, building links with scientists interested to work with them in this emergent research area of risk and

uncertainty in the semi-arid Tropics. At the time, some ICAR scientists linked quite actively into their meetings (see ICRISAT 1979 Workshop. However, the relationships between ICRISAT-AMD and AMD-IMD remained pleasant but rather disengaged (attendance of ICRISAT 1978i workshop).

Despite the work of agricultural economists that had begun to show the real problems behind vulnerability in scarcity areas, meteorological research never really linked up with these agro-economic studies, even inside the CGIAR institutes with divisions under one roof. Table 3.1 compares the different variables cited as appropriate for use in different fields of study, and column 1 is most significant for this chapter.

It is very common for agrometeorologists to lament the lack of soil and crop data available for their studies, so it is not surprising to see these in an optimal data set. However, section D – other useful research tools – focuses only on options to replicate tests: there is no idea to make comparisons with different kinds of farmers and their responses to drought. Thus application of agrometeorology was largely linked with the causes of agricultural drought - and remained largely divorced from study to see its potential consequences. Despite the wealth of information that could be monitored to understand drought and drought-proneness, most actual attention remained with rainfall, basic meteorological measurements for the assessment of evapotranspiration, crop yields at research stations, and crop returns reported from village authorities for the annual agricultural census. It is this gap on consequences that is studied further in Section 3.4.

Table 3.1 Different data sets cited as appropriate for research in agrometeorology, famine studies and social indicators of drought conditions

Data base considered 'optimal' for agrometeorological research (Huda et. al., 1978)	Causes of food scarcity and famine*	Social parameters used in the analysis of drought situations*
<p>A. Meteorological data Daily solar radiation Pan evaporation Maximum and minimum temperatures Daily rainfall</p> <p>B. Soil Data Moisture retention characteristics Depth Initial moisture and final moisture at harvest Moisture retention at least two other crop growth stages</p> <p>C. Crop data Dry weight Leaf area index Leaf number Light interception Days to flowering Planting date Plant population Row width and direction</p> <p>D. Other useful research tools Replication of crop trials More than one moisture treatment More than one crop cultivar</p>	<p>Total or partial failure of rain Uneven distribution of rain Untimely rain Excessive rain Flooding Tidal waves Epidemics Destruction by military operations Unsettled political conditions Inflated food prices Large-scale influx of scarcity-affected persons Heavy demand for food grains out of the district Rack-renting Destruction of rural food flows through new marketing systems Lack of non-agricultural wage earning opportunities Lack of social importance and political influence in obtaining food supplies Lack of invested capital or access to loans</p>	<p>Rainfall and water budget indicators of water deficit Reduction in yield or loss of crops Decrease in employment Decrease in wages Starvation deaths, and deaths from epidemics especially cholera, dysentery and malaria Loss of cattle due to fodder shortages Distress sales of cattle, farm implements and land Fall in prices for goods being sold Sale of ornaments and household possessions Inadequate foodstocks for self-provisioning Migration of cattle Theft of grass and food Emigration of persons in search of food and or employment Enslavement of children Postponement of all non-essential expenditure and reduction in consumption Increase in indebtedness Reduction in taxation under certain governance</p>

* Binswanger et al (1979); Borkar and Nadkarni (1975); Eusuf and Currey, 1979; Government of Maharashtra 1973; Sen, 1977;Subramaniam, 1975

3.2.3 State programmes and NGOs

Outside the scientific research agencies lay NGOs and state development agencies interested in water management for rural transformation. At this time NGOs were already active in construction of small dams and percolation tanks, and in local integrated watershed management for improved availability of water also managed locally for equitable water access. The best known model, called *Pani Panchayat*, developed special rights of access to water across a community, giving access to laborers as well as landholders and with rights based on family size and need rather than landownership (Pangare and Lokur, 1996).

At this time, the administration of state development programmes under the FYP lay with a District committee under the District Collector made up from relevant Ministries. The main drought recognition criteria remained related to crop yields – the *annewari* criteria¹ – when these were low, taxes were withdrawn and special relief programmes could be organised (see section 2.5.2). It was the 1960 Pardesani Committee that first defined the 'Scarcity Zone' on which Maharashtra Ministries and programmes would act – on the basis of frequency of *annewari* declarations. This failed to include any talukas in the districts of Nasik, Jalgaon and Dhule. While the Commission recognised parts of Dhule and Nasik had low rainfall, they did not suffer frequently from declarations of scarcity conditions (Government of Maharashtra, 1960).

When the Central Government introduced the DPAP, it used three quantitative criteria to define the areas for special Central assistance: annual rainfall; frequency of *annewari* (scarcity) declarations; availability of irrigation. However, the Maharashtra government,

¹The 'Famine Relief Code' of 1885 set up the *annewari* scale by which crops yields were compared to an official average for the local area. The *annewari* scale defined 'scarcity' conditions when relief or suspension of land taxes was granted if crop yields were poor, with relief and public works scheduled accordingly. This is why raingauges are often sited at Revenue Circle offices. *Annewari* declarations are still made annually for revenue purposes.

conducting its own analysis for a state DPAP in 1973, focused primarily on rainfall and questioned the suitability of *annewari* criteria for its 'moral hazard' (as data open to abuse). They defined the 'scarcity' zone to include all unirrigated areas (less than 15% under irrigation) receiving less than 750 mm annual rainfall (or 800 mm in shallow soil areas). This later 'scarcity zone' did include talukas in Nasik, Dhule and Jalgaon districts. In 1960, much of Dhule at least was seen as remote and underdeveloped with tribal settlements, with little regular cultivation on which land taxes could be levied or assessed. Use of only rainfall criteria brought into the DPAM an area which did have drought risks, but which were different from those of the long-known scarcity districts.

Ironically, as the economic and political need for a broad development programme for the DPA became accepted, so the arguments proceeded for rigorous assessment criteria, 'free of moral hazard' to assess these areas. Despite the objectives of the DPAP being couched in the broadest economic and ecological terms², no changes were made in monitoring or assessment criteria. Nor did the research attention shift much beyond the yields and planting options in agriculture. The definition of regions for state action adopted technical criteria consistent with ideas from scientific agencies available, focused on rainfall available, and not to wider cognition of the production problems of the DPAM. Critical analysis of the value of this annual rainfall criteria became the first of my own studies, to analyse the relevance of boundaries subsequently mapped for agricultural development, and what tools might bring better representation of actual realities.

Figure 3.2 shows the general boundary of the DPAM in relation to the state as a whole and the network of agricultural research centres and regional colleges of the Agricultural University. The state research centres were focused on specific crops

rather than having a general focus on local production. It also shows the 500 mm and 700mm isohyets for average annual rainfall. Fig. 3.3 shows the boundary of the DPAM in more detail, together with the sites of the rainfall stations used in the studies discussed in this chapter.

The DPAM shows the association of the area with this lower rainfall that occurs particularly in the lee of the Western Ghat mountains: shallow soils and certain kinds of dryspell risk shape the risks of crop failure and vulnerability to drought of areas outside this isohyet. Irrigation development explains the areas within the 700mm isohyet that are not demarcated as droughtprone³.

The complexity of the resulting landuse created by this interaction of dryland and irrigated areas, and funding from different programmes, has shaped the politics of drought and water access virtually since the state came into existence.

3.2.4 Monsoon dynamics and rainfall across the DPAM

The rainfall received across Maharashtra is related to the establishment, location and shift of the low pressure area known as the monsoon trough aligned generally north of the Bay of Bengal – south of Lahore. It is the speed of synoptic change in June and July that gives the distinctive onset and burst of the ‘southwest monsoon’ rains over India. The rainfall during onset and across the monsoon season results partly from continental

² (i) to reduce the severity of impact of drought; (ii) to stabilise the incomes of people, particularly weaker sections of society; (iii) restoration of ecological balance.

³ These include lift systems and gravity systems along the Tapi river in the northern boundary, and irrigation systems developed in the upper tributaries of Eastern flowing rivers, including along the Godavari river flowing through Nasik and north of Ahmednagar (the Mula irrigation system) and various tributaries of the Krishna river flowing across southern Maharashtra supporting irrigation in Pune District (the Nira irrigation system) and Sholapur (including lift and gravity systems supplied by the Bhima and upper Krishna rivers).

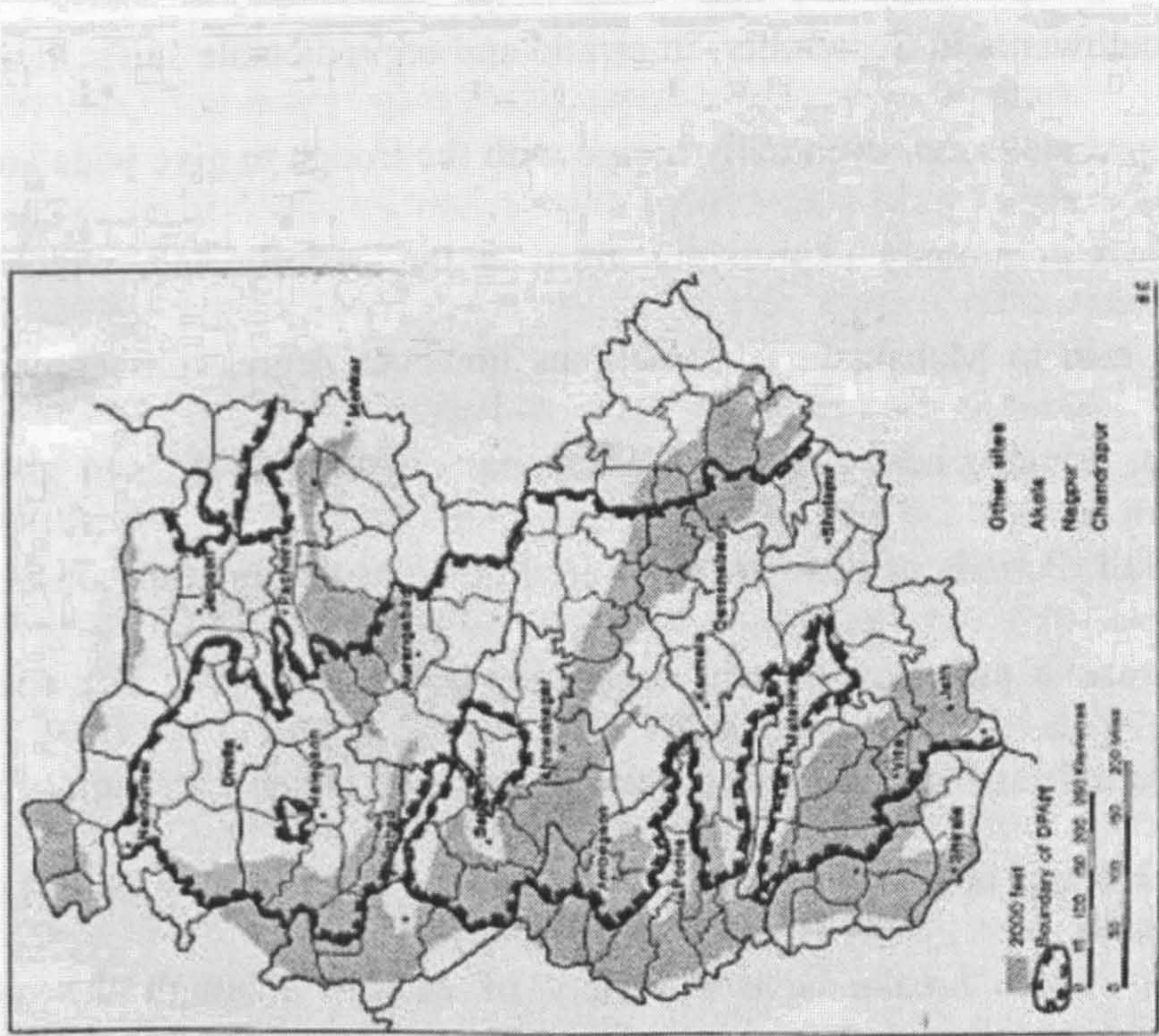


Fig 3.3 Detailed map of the droughtprone area and raingauge sites used in analysis

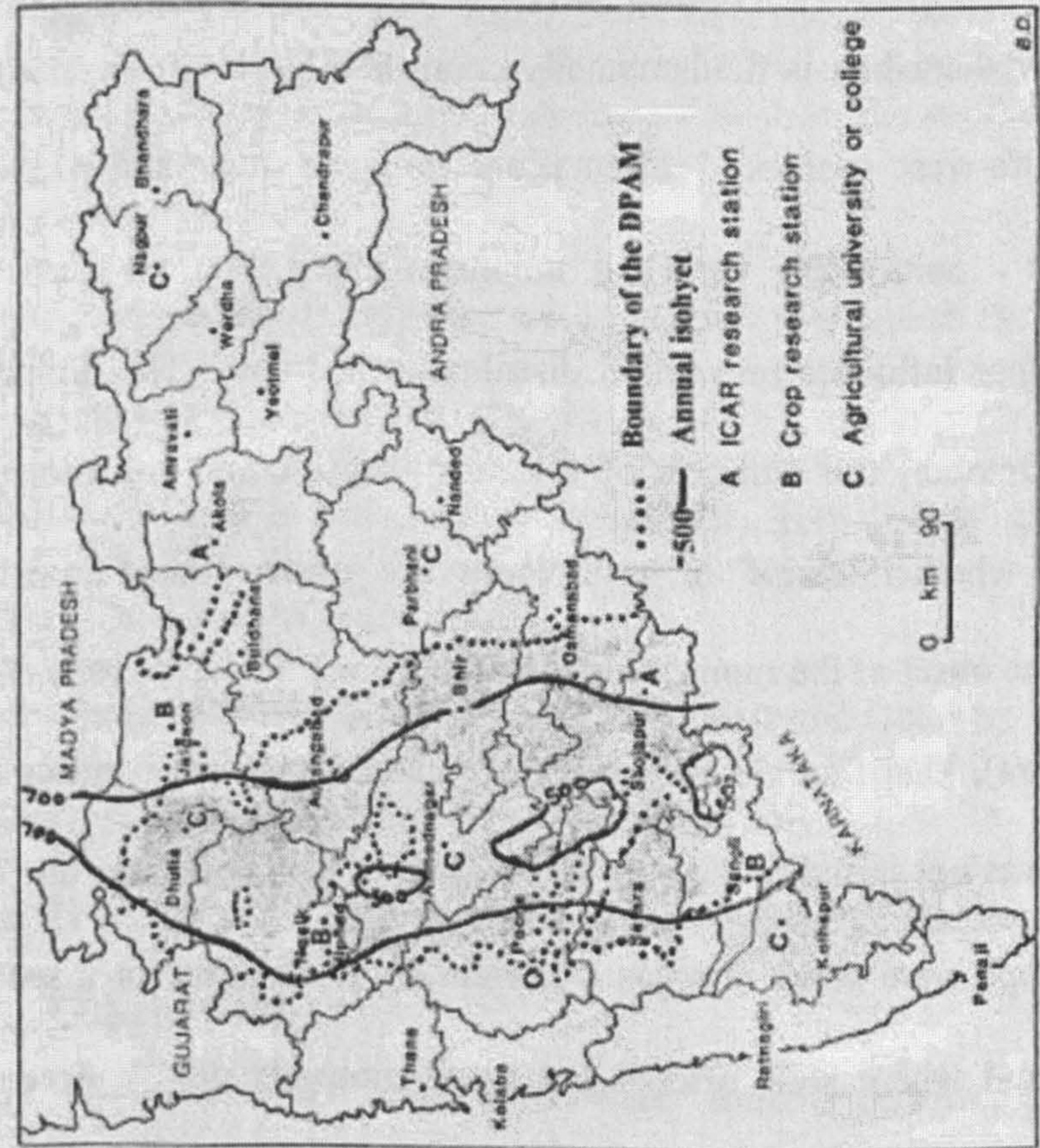


Fig 3.2 Maharashtra state and districts, showing the boundary of the droughtprone area and selected isohyets

relief effects but also from disturbances and depressions in the moisture-laden airflow. This trough moves southwards in September, in erratic and unpredictable shifts. It also steers the tracks of depressions that eventually merge with the trough to give wide areas of heavy rainfall. Most commonly depressions form at the easterly end, which in September can bring rain to Maharashtra. Sometimes however depressions come in from the Arabian Sea, bringing heavy rain to western parts of the DPAM and giving much trans-Ghat rainfall. Periods of heavy rainfall are known as active monsoon days, and many now recognise a pulsation in rain suggesting a 5-9 day cycle. Dry spells between these rainy periods are common. Most serious, however, is the condition of the 'break monsoon', which can bring dryspells of 3-4 weeks or more in July or August (see Hamilton, 1977). These breaks have a variety of causes, although the most common is when the monsoon trough shifts north of the Himalayas.

Crop production in Maharashtra is fundamentally controlled by this onset, passage and retreat of the 'south-west monsoon' circulation, between June and October. However, relief features - particularly the Ghat mountain chain with its spurs and outliers - also have a major influence on rainfall distribution and soils. The timing of the rainfall peak June-October, the duration of the rainy season, and soil moisture characteristics determine whether 'kharif' or 'rabi' crops are grown. Kharif crops are sown in June/July with the onset of the monsoon rains. The principal kharif crops of the DPAM were: millet (bajra), kharif sorghum (jowar), groundnut, sesamum, pulses and cotton (although cotton was not raised in the core DPAM), and usually shorter duration pulse varieties. Rabi crops were sown in areas experiencing peak rains (or a second peak) from September and where soils offered good soil moisture storage potential beyond the cessation of the rains. Principal rabi crops were sorghum, gram and safflower, with some wheat grown in the cooler northern areas if irrigation was also available. A cropping calendar is given in Appendix 1. Apart from cotton and

groundnut, all other crops were intercropped, a traditional farming practice. Fig 3.1 shows the main cropping regions, together with relief features.

Most of the northern, western and eastern state has a single rainfall peak in July, and has always grown kharif crops. In areas with a short rainy season and shallow soils, millet and short duration pulses were the only crop options. Central and southern Maharashtra, and the DPAM, had a bimodal rainfall regime with a distinct August minimum. This 'break' in the monsoon circulation gave farmers a low expectation of four consecutive months of rainfall, and farmers opted for either a short duration crop raised June-September or waited for the September rains. Opportunities for double cropping were limited, except where catch cropping was done with short duration pulses in the kharif season. Locations with a high expectation of 5 months of adequate moisture and good soils went under kharif sorghum or cotton.

I thus differentiated 7 types of drought risk from the southwest monsoon – all with different implications in agriculture:

1. complete failure of the monsoon circulation to establish itself;
2. late onset of the monsoon, after the middle of July;
3. dryspells in July and August (in kharif), from 'break' conditions, or dry spells between disturbances;
4. dryspells between disturbances in September and October;
5. inadequate rainfall in showers to replenish soils;
6. early withdrawal of the monsoon circulation before October;
7. spells of bad years.

By this time IMD and ICAR were already performing analyses of Moisture Availability Indices (see section 2.5.2 and 3.4.2) to assist planning of new production – particularly for onset conditions, and probability analyses that showed different levels of

reliable rainfall across the season – the rainfall that was received at 30, 50, and 70% levels. However, while all these drought contexts were acknowledged as constraining production, there were no real analyses of drought events or sequences of adequate or insufficient rainfall across a season, that shaped risks to farmers. These gaps shaped my focus onto dryspell analysis. The cognitive focus in IMD and ICAR - that water availability was the key factor shaping development, and that only scientific analyses were reliable, based on their own collected data - focused them into studies using precipitation alone, or into comparing precipitation and evapotranspiration. The next two sections summarise the main analyses undertaken by IMD and ICAR with these different data sets, and also my studies of dryspells to understand relative risks of different problems and the vulnerability in the farming system,

3.3 PRECIPITATION ANALYSES TO STUDY DROUGHT AND PRODUCTION PROBLEMS IN THE DPAM

At the start of my 1978 study, a range of precipitation criteria were in use to indicate dry conditions for different time units. These are summarised in Table 3.2., which indicates several generic criteria already established to define meteorological drought. My interest, however, was to understand criteria to help map vulnerability and assist regional development planning in the DPAP.

3.3.1 Boundary criteria and spatial variation

The simplest drought risk criteria were the annual totals of rainfall: these gave overall indications of drought, but did not separate out effects for kharif and rabi crops, nor did they show timing of critical drought periods.

Table 3.2 Rainfall criteria used to classify drought prone areas and drought periods

I. Criteria based on the amount of rain.

(a) Annual amounts

Drought areas

- (i) 400-1000mm⁴
- (ii) less than 750mm, or less than 800mm in shallow soil areas³

Drought years

- (iii) 'drought years' receive less than 500mm⁴
- (iv) 'serious scarcity years' receive less than 385mm²

(b) Drought periods

- (i) 4 or more consecutive 'dry' weeks (weeks with less than 18mm)¹
- (ii) an 'absolute drought' begins when at least 15 consecutive days have occurred with less than 0.01 inch on all days³
- (iii) 'partial drought' occurs if there are at least 29 days, over which the mean daily rainfall is less than 0.01 inches²
- (iv) 'dry spell' is a period of at least 15 consecutive days, none of which has received 0.04 inches or more²

II. Criteria based on statistical variability

(a) Annual rainfall

Drought areas

- (i) a 'drought prone area' is one where the probability of a 'drought year' (see iii) is over 20%²
- (ii) a 'chronic drought prone area' is one where the probability of 'drought year' is over 40%²

Drought years

- (iii) a 'drought year' occurs when less than 75% of the 'normal' rainfall is received¹
- (iv) a 'severe' drought year occurs when less than 50% of the 'normal' rainfall is received¹

(b) Drought periods

- (i) "the seasonal rainfall is more than two standard deviations below normal"³
- (ii) "crop failures are general when more than the 22 monsoon weeks have less than half the 'normal'; rainfall of those weeks"¹

(c) Drought weeks

- (i) rain is 'scarce' when below the 50 per cent probability given by the gamma function⁴
- (ii) a drought week is one which receives less than half its 'normal' rainfall, where the 'normal' is at least 5mm¹

Sources: 1. India Meteorological Department, 2. British Meteorological Office. 3. Government of Maharashtra (1973), 4. Verma. (1976)

Mapping with annual rainfall criteria

Across semi-arid areas, the figure of 700-800 mm was in widespread use as an average rainfall total indicative of restricted cropping options, and indeed had been used by the state government in its work (see also Fig. 3.2). I also performed analyses with the 750mm annual isohyet for the selected rainfall stations (1901-1976). I found that for basic mapping this criterion did provide a fairly representative boundary for the DPAM, as it is linked to the reliability of water requirement for a range of dryland crops. As such this boundary did indicate the area of most limited production possibilities – although less useful on the eastern side because such a parameter could not distinguish kharif and rabi risks. Fortuitous or not, it appeared that this annual isohyet correlated very well with areas that frequently suffer long dry spells in August-September. - but it was this, rather than low rainfall per se, that often restricted production possibilities.

Two other annual rainfall criteria had also been used quite successfully to indicate further production stress. Mallik and Govindaswamy (1963) used parameters of 500mm annual rainfall for a drought year, and 385mm for a serious drought year, as mapping criteria across India. I also used these parameters in a very simple first study of probability of dry years, and runs of bad years, as these precipitation totals are linked to minimal water requirements for crops like sorghum and millet to survive, with results as shown in Tables 3.3 and 3.4. The DPAM stations of Malegaon, Ahmednagar, Sholapur and Aurangabad showed the highest probabilities risks of these low rainfall totals and runs of dry years, and were thus selected as key sites for later detailed risk studies.

Table 3.3 % of years 1901-1976 when annual rainfall was less than the following

	500 mm	385 mm
Malageon (DPA)	38.1	18.4
Ahmednagar (DPA)	30.2	13.1
Sholapur (DPA)	19.7	7.9
Aurangabad (DPA)	11.8	6.5
Poona	17.1	3.9
Jalgaon	5.2	-
Akola	2.6	-

Table 3.4 Frequency of spells of years where annual rainfall was less than 500 mm (1901-1976)

Length in years	1	2	3	4	5	>5
Malegaon (DPA)	9	5	1	1	-	1
Ahmednagar (DPA)	11	6				
Sholapur (DPA)	9	3				
Aurangabad (DPA)	7	1				
Poona	10	-	3			
Jalgaon	4	-				
Akola	3	1				

Mapping precipitation frequencies and probabilities within the monsoon season

By 1978, Biswas and Khambhete had used the gamma function to analyse weekly rainfall probabilities across Maharashtra, publishing probabilities for the 70%, 50% and 30% levels. These provided a good picture of spatial contrasts across the state in a given meteorological week⁴, and of numbers of weeks with a higher probability of receiving rainfall, but the data was not related to time of onset of the monsoon. I did no further probability studies of this type, as I thought simpler criteria were sufficient for basic mapping of water insufficiency.

3.3.2 The differential incidence of drought through the monsoon in the DPAM

Studies had been done to identify criteria to signify late onset of the monsoon and examine frequency of dry spells – but these were done to find general criteria, and no studies had been focused on the DPAM. I reviewed the criteria around planting dates, but decided to study these with a fuller set of agrometeorological data, as reported in section 3.5.3. However, I did work further to study dry spells in rainfall.

Onset conditions and sowing rains

Criteria to identify onset conditions of the monsoon had been identified by Raman (1975) for Maharashtra generally, and Virmani (1975)⁵ for Hyderabad, Andhra Pradesh. A comparison of these criteria for Maharashtra study suggested that onset criteria are locally specific. Use of the Hyderabad criteria in the DPAM tended to pick out the heavy pre-monsoon showers in advance of the real onset of rains, common in Maharashtra in the months of May and June.

Raman (1975) put forward the idea of the 'sowing rains' of the first heavy rain that would saturate a soil in preparation for seeding. He looked for a criterion which would identify both the substantial rain which typified transition into the monsoon, and a sustained wet period where moisture could percolate to sufficient depth to moisten the soils and allow land preparation for crops. His criteria for the commencement of sowing rains (CSR) was a seven day period when at least 25mm fell, with 1mm or more on any 5 of these days. Research at Sholapur confirmed that shallow soils

⁴ All weeks of the year were numbered: the first week of January was Met week 1.

⁵ The criteria used by Virmani (1975) was to identify the specific 'meteorological week'⁵ where at least 20 mm of rain is received over two consecutive days in a week. However, this week must also be one with a 'dependable precipitation probability' of receiving 10mm of rainfall. This gives the media sowing date for Hyderabad as 25 June – 1 July (met week 26), which is similar to the DPAM.

required about 25mm rain to be moist enough for tillage. Heavier soils required up to 50mm before tillage can take place.

Raman's study of the sowing rains across Maharashtra showed that the DPAM was characterised by a median onset date of 24 June-1st July, with the most delayed onset in isolated pockets of north-east Ahmednagar and west Sholapur - with variability around this median date of up to 26 days. The date of onset was strongly influenced by relief. The Dryland Research Station had a simple classification that 'late sowing conditions' occurred when the rains started later than 15 July (Met week 28). If CSR occurred after this, then crops like bajra, green gram and groundnut were highly likely to fail. 'Mid-season' correction crops like setaria, sunflower or castor might be more successful.

Planting dates in the first fortnight of September (Met. Weeks 36 and 37) were considered ideal for rabi jowar and safflower. Rains after 1 October were regarded as late. If sowing was delayed after 20 October (after Met. Week 42) then very poor yields were expected. With late rabi sowing dates, the cooler December weather could encourage unwanted tillering which decreased yields from a sorghum crop. The cooler weather was more marked in northern Maharashtra, so that if a rabi crop was grown it was usually wheat (not planted until November, to encourage tillering). My own study (see 3.4.3) suggested that late rabi planting conditions occurred more frequently than the very long dry spells that can threaten kharif crops. Also, late rabi rain was less of a risk than general depressed yields resulting from restricted soil moisture availability.

Dry spells and their links with the August 'break' and rabi rains

Dry spells were one of the major risks in kharif crop production, and several general studies of dryspells in the monsoon had taken place for Maharashtra before mine. The first difference in debate had been over what constitutes a 'dry day' and how a dryspell is known to have ended. The IMD classified days with at least 2.5mm as 'rainy days'. Raman (1974) suggested that at least 6.3 mm was required for effective moistening of the soils in the Indian climate. Raman also considered termination of a dry spell in his study. He studied the duration of dry spells between the first sowing rains, and the next seven day period when 2.5 mm or more was received, and then estimated the probability that the spell would be 20 days or more. His 30% probability contour picked out the DPAM almost exactly, with two core areas – Nasik-Ahmednagar and Western Sholapur district - having a probability of 60% of such dryspells.

Chowdury et al. (1976) made a study of dry spells at 26 district stations across Maharashtra for the period July-October. Their maps showed the DPAM to be characterised by longer breaks between showers, whereas districts further east had more reliable rainy periods broken by spells of only 1-5 days. In particular, their map of the frequencies of dry spells of 15 days or more (with 6.3mm as a wet day criteria) gave a close approximation to the core 'scarcity zones' defined by the Pardesani Committee (1960) and the OMAI criteria of Biswas and Sarkar (1978) (see section 3.5). However, I felt that more differentiation could be gained by studying detailed dryspell patterns within different months, for more stations within the DPAM. This was done partly to ascertain which dryspell criteria gave the clearest picture of risk variability, However, it was also done to understand how, when a dryspell established itself, it tended to persist.

A variety of mathematical series were available to model the frequencies and probabilities of spells of 1,2,3....t days (Lawrence, 1957; Buishand, 1977). However,

beyond a mathematical question of what mathematical series might represent actual probabilities, there is the question of what kind of knowledge is wanted. Information on persistence of dry spells is very relevant to climatic forecasting once a spell has started. However, such studies are less useful to understand the frequencies and risks of dryspells of certain lengths around which cropping could be planned by farmers. In conventional statistical analysis of runs of dry days of 1,2,3...t days, the higher general frequencies of very short runs in a month can easily hide understanding of the recurrence of what longer lengths of spells in a month over a period of years. After review of the assumptions and uses of different statistical approaches and mathematical series, and returns relative to higher levels of computation demand (see Appendix 2), I calculated two parameters from the compilation of actual frequencies of spells 1,2,3..t days for the period 1901-1976. Following the convention of Lawrence (1957), spells that ran across months were allocated to the month that received the greater part of the spell. Following IMD practice, the criterion for a dry day was a day receiving less than 2.5mm of rain. The two parameters were calculated were:

- (i) the average length of spell t occurring an average frequency of 50% in a month

$$\frac{\text{Number of dryspells of at least.... t days in month}}{\text{Number of years (n)}} = 0.5$$

This spell was labelled (S₅₀)⁶

- (ii) the persistence probability (P_t) that if day 1 is dry, then days 2,3,4.....t days will remain consecutively dry, where P_t = p₂p₃p₄...p_t

$$p_t = \frac{\text{number of spells lasting at least t days}}{\text{number of spells lasting at least (t-1) days}}$$

$$\text{e.g } p_5 = \frac{\text{number of spells lasting at least 5days}}{\text{number of spells lasting at least 4 days}}$$

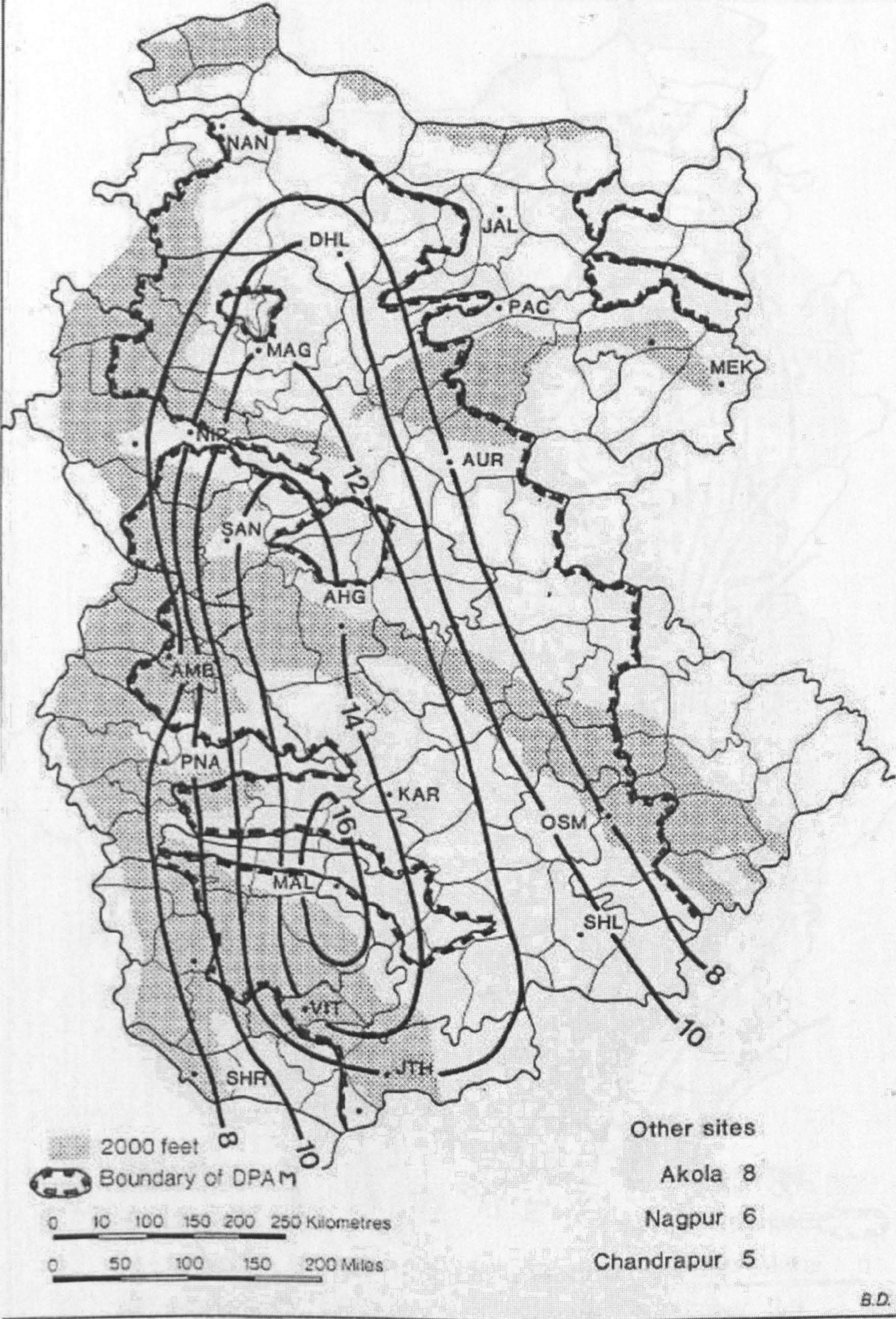
⁶ The probability of a dry spell of x days in a month can also be derived from calculation of the return period, by ranking (1...m) the maximum dryspell lengths per month over N years, where P = m_x/(N+1)

The frequency tables and probability values given above were calculated for each month at the 22 stations shown in Fig 3.3. Tables presenting the frequencies of spells of at least 5, 10, 15, 20, 25 and 30 days are given in Appendix 2, which also gives further discussion of the methods selected and also more detail on the most useful criteria found for each month. Some results are presented here as maps and graphs, as these provide better synthesis of data. The maps presented focus on the DPAM, to present data on the largest possible scale, but results from three non-DPA locations of Akola, Nagpur and Chandrapur are listed for contrast in the lower right-hand corner.

Further study of the persistence probabilities gave information about the duration patterns for spells of 2,3,4....t days were plotted for July and August, for six representative stations – Malegaon, Sholapur Sangamner and Jath in the core drought area identified by the above maps, and Akola and Aurangabad outside this core area. Two aspects of this persistence were important:

- i) the actual value: a high value, for example over 0.8, indicated that a high proportion (80%) of spells extend for at least one more day;
- ii) the trend of a series of persistence probabilities, which could be positive (upward), negative (downward) or stay fairly constant (see Lawrence, 1957). A positive or constant trend suggested a dominance of synoptic features which tended to promote spells of this length. A downward trend reflected a rapid falloff in the frequencies, and indicated the rare occurrence of atmospheric phenomena responsible for dry spells of this length

In the maps for August, contrasts between DPAM and non-DPAM stations were very marked: Malegaon, Sangamner and Jath all showed stable or positive persistence probabilities to P_{20} and beyond, all probabilities being over 0.8. At all these stations there was thus a high chance that a spell, once started, would persist into this length range. These three stations then showed a period of negative persistence before showing a second period of positive persistence towards the length of maximum spell. The variation in the



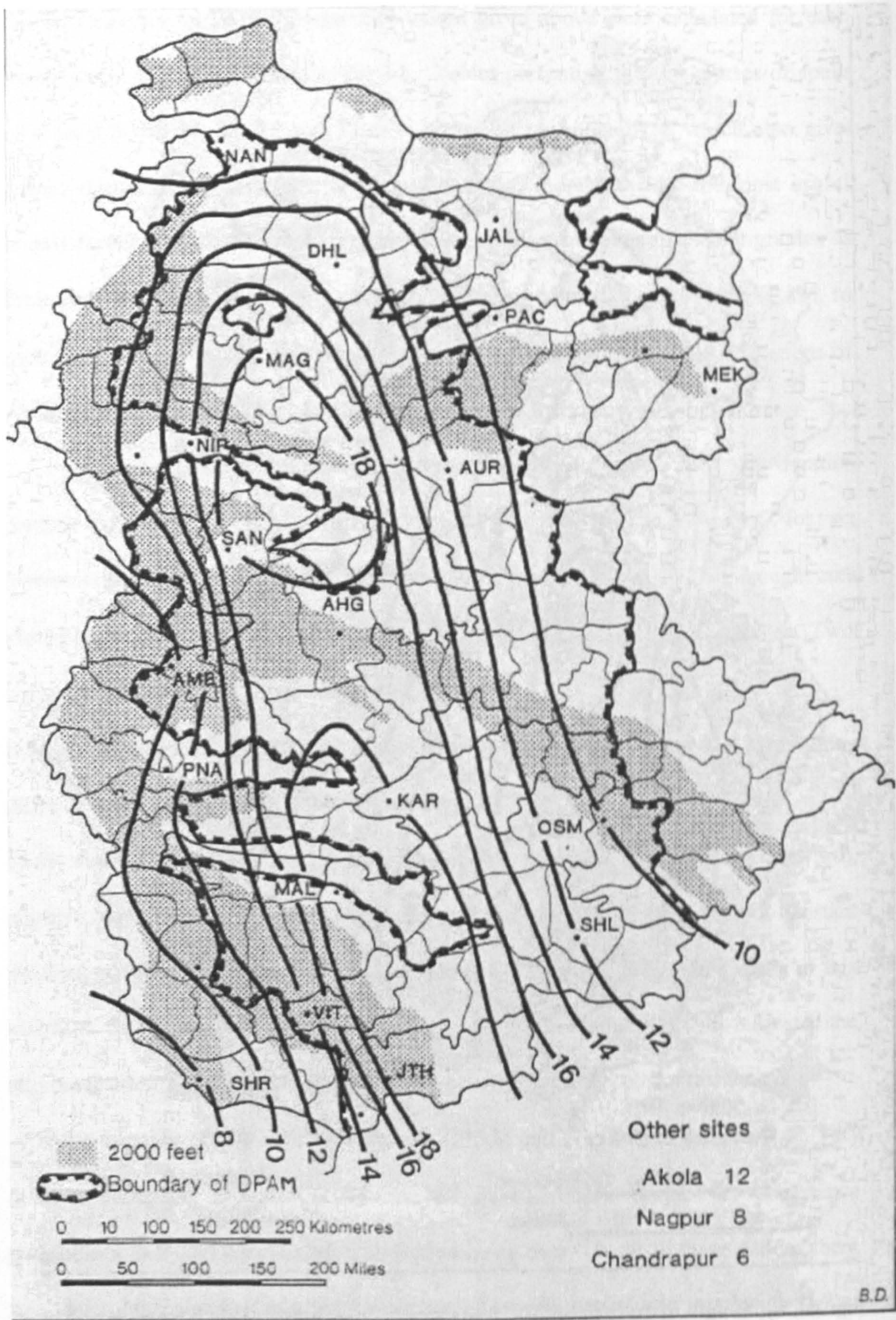


Fig. 3.5 S_0 Length of dryspell occurring in 50% years in August (Isolines indicate spell length of at least t days) (1901-1976)

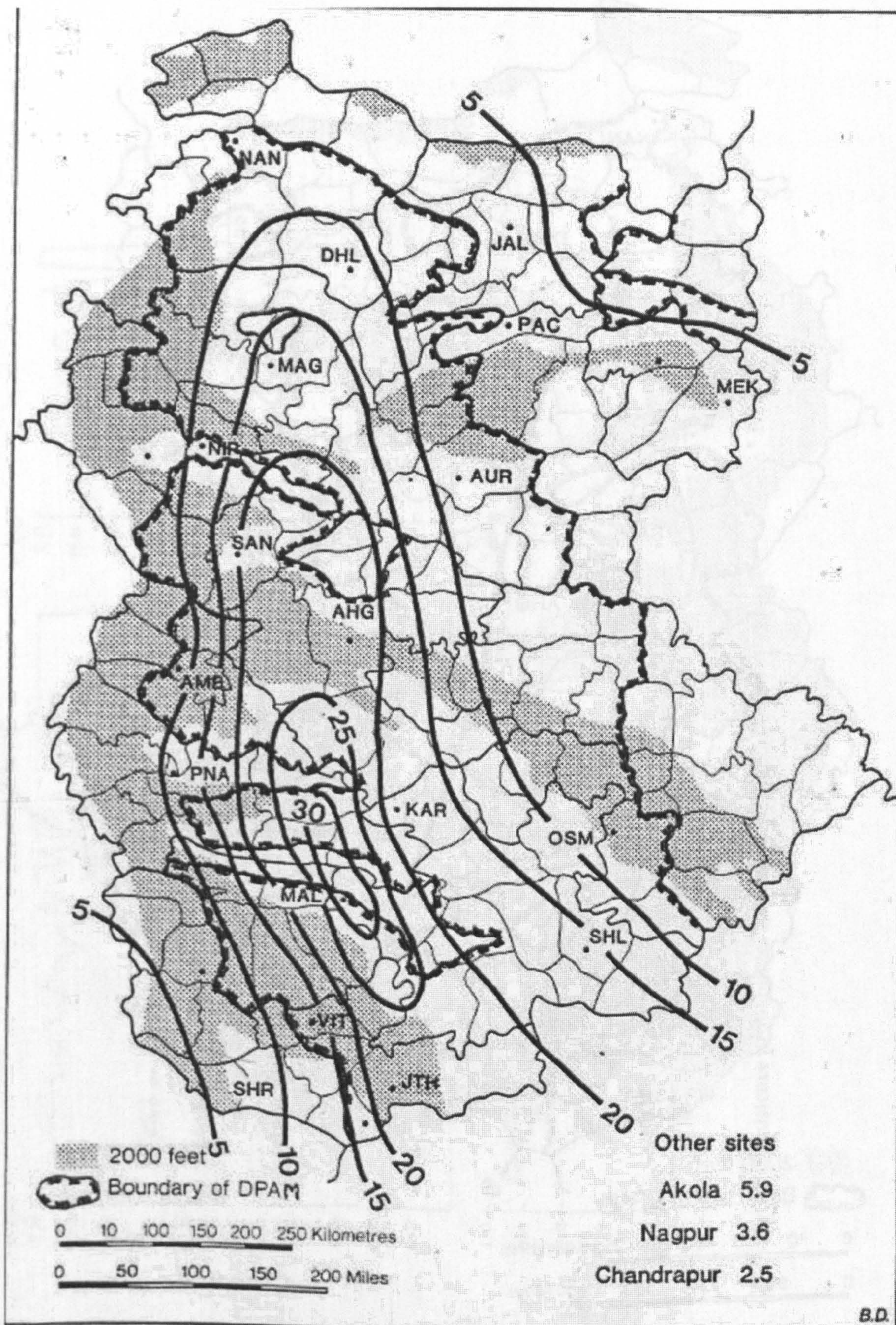


Fig 3.6 Probability P_{10} in July expressed as a percentage, the probability that a dry day persists as a dryspell of at least 10 days (from rainfall records 1901-1976)

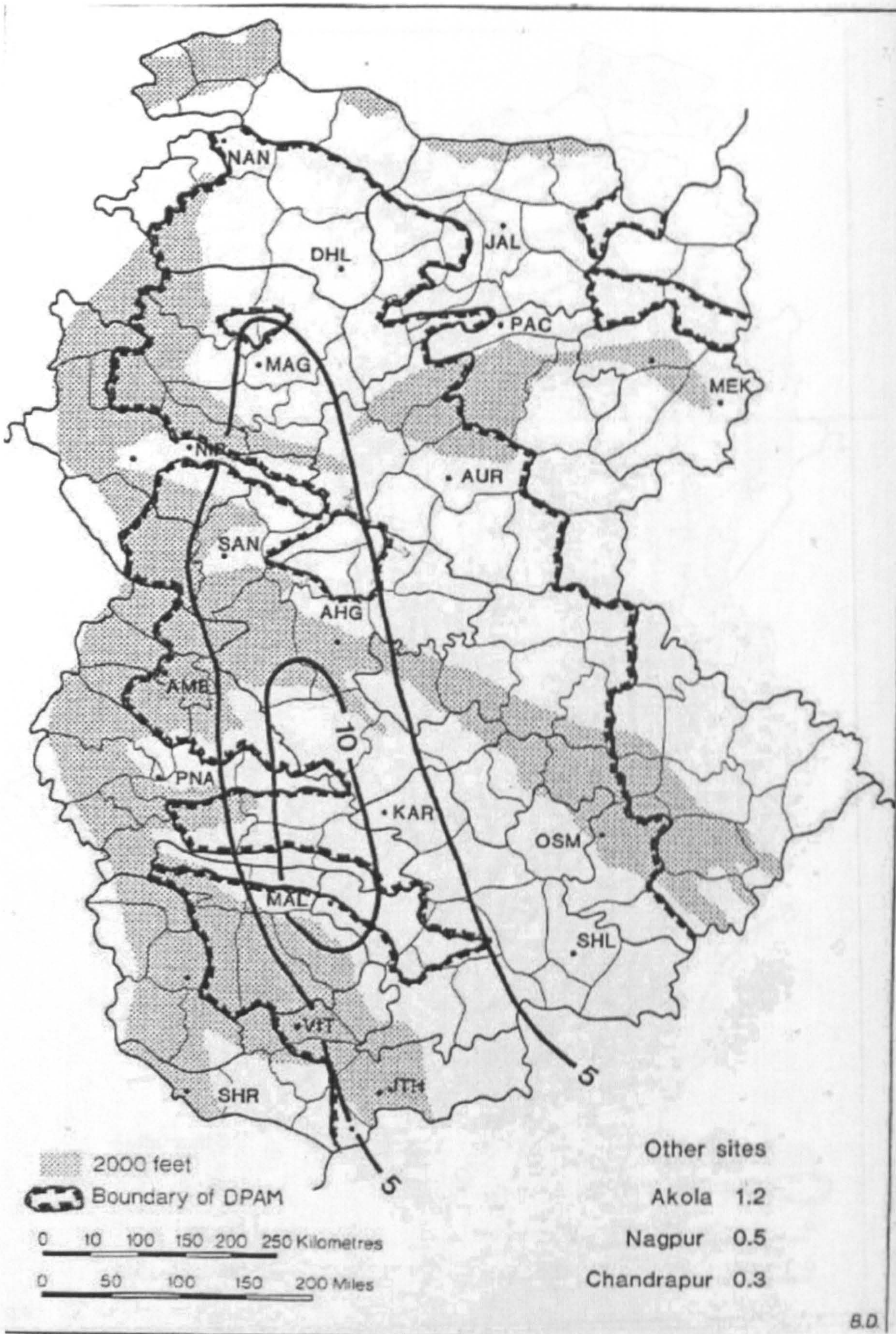


Fig 3.7 Probability P_{25} in August expressed as a percentage, the probability a dry day persists as a dryspell of at least 25 days (from rainfall records 1901-1976)

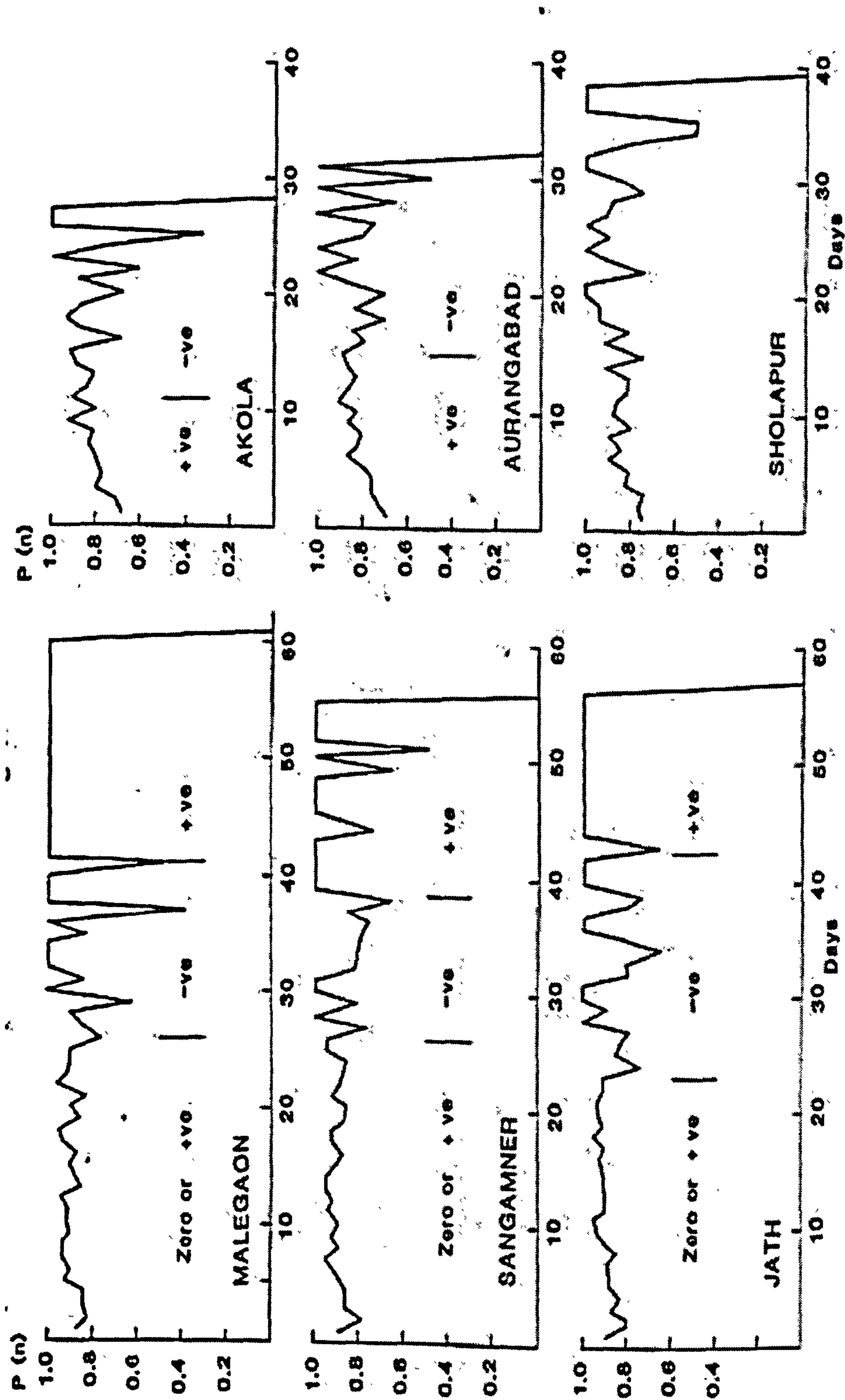


Fig 3.8 Persistence probabilities for August, selected DPAM stations.

longer duration of spell was influenced by the presence of only few spells. Nevertheless there was a suggestion of two modes in dryspell length which might well reflect the 'typical' length of break monsoons in August i.e. frequently up to three weeks, less frequently three-six weeks, and then again six-eight weeks. At all other stations, the first positive persistence period was much shorter, with a change in gradient around P_{10} - P_{15} . Neither Aurangabad or Akola showed this tendency to experience the second, long type of break that sometimes occurs at the core DPAM stations. This supported my idea that it could be a quiescent period following the decay of an Arabian Sea disturbance, particularly when it merged with more general 'break monsoon' conditions, that caused such severe dry spells in the western DPAM. The graph for Sholapur had less specific trends. There was a period of general persistence up to about P_{22} , but there were breaks in this trend P_{10} - P_{15} . The suggestion was that Sholapur behaved like the other core stations in some years when it did experience long dry spells. In other years, however, Sholapur experienced weather much more akin to Aurangabad, and might miss some of the more disastrous spells of the more Western stations. This again helped justify consideration of rabi cropping options.

These dry spell analyses not only provided a great deal of information on useful mapping criteria, and the nature of risks at certain sites. They also emphasised the need for improved crop strategies to be evolved and tested relative to these longer dry spells - with moisture stress the yield advantages of hybrids will not materialise. Moreover, they provided a great deal of information relative to weather forecasting zones in the DPAM. This suggested that six weather zones existed in the DPAM, as shown in figure 3.1, a much finer breakdown than was being used by IMD at that time (see Appendix 1) and developed in the OMAI study of Biswas and Sarker (1978) discussed in the next section.

Other studies

Even in the 1970s, there was concern whether climatic change was occurring and rainfall becoming more precarious. Mann (1955), Jagannathan and Parthasarathy (1973) and Verma and Robertson (1973) all searched for trends and periodicities in Indian rainfall: while none have found trends, all found periodicities and 'persistence' effects in rainfall patterns between years. I also looked for periodicities in rainfall using 5-year moving averages. This certainly suggested that periodicity and persistence were present in the evidence of bad years, although their incidence was irregular. While trends were not apparent in most of the DPAM stations, results suggested that Sholapur had been receiving better July and August rainfall in recent years, which was relevant for the kharif cropping strategy being promoted by the ICAR Sholapur research station.

3.4 WATER BALANCE ANALYSES FOR DROUGHT RESEARCH

Whilst rainfall studies can provide simple criteria by which to assess drought, most workers agree that analysis of rainfall in relation to crop water demands provides a much more rational approach in agricultural drought analysis. In their simplest form, water balance models are a book-keeping procedure between rainfall, evapotranspiration and soil moisture. Most models use potential evapotranspiration data, either from instruments or formulae. Actual evapotranspiration from specific crops may be estimated by lysimeters, or soil moisture or neutron probes, or from formulae developed by workers such as Penman or Thornthwaite. A good summary of models can be found in Doorenbos and Pruitt (1975).

3.4.1 P:PET ratios versus crop weather models

By 1978, potential evapotranspiration (PET) data (Penman formula, albedo 0.35) had already been derived from 18 'agromet' stations across Maharashtra: monthly averages were published for all these stations, and weekly averages were also available for 11 stations. The IMD had started maintaining lysimeters to study sorghum growth at Akola and Sholapur, from which actual evapotranspiration was estimated, but data were still limited. Thus water balance models were restricted to those that could be built around average PET estimates.

Crop weather models which related soil moisture stress at crop growth stages and crop yield were another focus of international scientific interest, also as particularly relevant for monitoring yield stress on crops raised on stored soil moisture. Crop weather models have two components: building a realistic model of soil moisture behaviour, and relating this to known phenological crop growth stages and research on yields. More sophisticated crop yield models could be built if daily measurements of leaf, root and plant data were available (see Shaw, 1978; Maas and Arkin, 1978), but most scientists were struggling to find models that worked with less data. Doorenbos et al (1979) provided a simplified model for estimating crop yields under moisture stress, using evapotranspiration and soil water data only, for a variety of crops including sorghum, groundnut and cotton. Another model in wide debate was the Australian CSIRO model 'WATBAL' (Keig and McAlpine, 1974). In the WATBAL model, water available is indicated in the soil profile at a specified depth (which can be related to rooting depth), and is released at a rate which depends on soil saturation status, which then modifies the transpiration rate of the plant. In turn, as the plant removes water from the soil, a 'soil factor' reflecting the moisture status of the soil can be derived.

The main problem for even a simple crop weather model in India was the shortage of information on the behaviour of soils and crops. ICRISAT successfully adapted the WATBAL approach to derive probabilities of soil/crop moisture stress. They built in other local measurements to provide information on plant stress, of which stomatal resistance and leaf water potentials proved to be good indicators of soil moisture stress – by now also equipment was available for their measurement. However, instruments to measure such parameters were not available at meteorological stations nor at many of the national or University research stations. ICRISAT staff developed a set of field experiments to model hybrid sorghum production in collaboration with various universities (but not in Maharashtra). However, all experiments were on hybrid varieties produced under fairly optimum conditions. There was no monitoring of actual production on a farmer's field in a drought area. No studies existed then on the drying behaviour of Maharashtra soils, so I constructed a simple crop weather model, drawing on 'generic' equations for the modelling e.g. Shaw (1978) suggested generalised rates of provision of water under high, medium and low evaporation rates. The IMD had never attempted to experiment with such models. It stayed simply with the data that it collected from its own stations. All its work in relating weather and crop growth was done through regression equations: no simulated crop modelling had ever been undertaken.

Thus, in my study, I did pursue more detailed work with both simple water availability criteria equating rainfall and evapotranspiration, and also experimented with building a crop weather model for sorghum using data from Sholapur. For this I enlisted the help of a programmer. I tried to monitor the number of weeks in each crop development stage where soil moisture was likely to cause decreased yields. The results I obtained were puzzling in the extreme, suggesting no real difference between soils of considerable different depths. Later a colleague testing the model warned me that one sub-routine was

not looping correctly, and that the programming was faulty. This experience taught me that it is better to use only tools you construct yourself, and to be cautious with models that combine generic or surrogate data from different general sources. Thus I came to respect the attitudes of IMD and ICAR to only use their own data, only use field measurements without simulation, and use data compiled over consistent periods at the same location. I also came to recognize the warning of Funtowicz and Ravetz (1990) about the problems possible from uncritical use of computer models and programmes.

3.4.2 P:PET ratios and crop options

The simplest crop water balance model is a ratio of potential evaporation (PET) to rainfall (P) to define growing periods (Cocheme and Franquin, 1967):

<u>Period</u>	<u>P:PET ratio</u>
humid	>1.0
moist	0.5-1.0
moderately dry	0.25-0.49
dry	<0.25

Humid and moist periods (i.e. ratio P:PET of 0.5 or more) are considered suitable for plant growth. Raman and Srinivasamurthy (no date) defined average growth periods for 21 stations in Maharashtra, comparing average monthly rainfall with average monthly PET. The moist and humid period lasts on average 130-150 days over much of the Drought Prone Area (long enough for a sorghum crop). However, at several stations it is 90 days or less, and parts of Poona and Ahmednagar have almost no humid period – suggesting conditions always likely to give depressed yields. This simple comparison was also used by Gadre and Umrani (1972) to map detailed contrasts for crop planning across Sholapur district. Srinivasa Murthy (1976) also used this approach to study risks for crop production at six Maharashtra stations, mapping actual weekly rainfall data year by year against average potential evapotranspiration for

a 50 year period, to understand more about the growth periods of bajra, kharif jowar and rabi jowar. This work was one of the first by AMD-IMD staff to distinguish the relative risks to kharif and rabi crops rather than map only the monsoon season as a whole. His work showed the less favourable kharif cropping opportunities at Ahmednagar and Sangli, where general production opportunities were also at their lowest. His work also confirmed the more favourable conditions for cotton production at stations like Jalgaon, Aurangabad and Akola.

More recently workers had begun to use the 'moisture availability index' (MAI) of Hargreaves (1967) on a weekly basis to study agricultural planning. As already noted in section 2.5.3, Hargreave's ratio was the ratio of 'dependable precipitation'⁷ (defined by him as the rainfall amount received at 75 per cent probability) to PET. The probability that this ratio is at least 0.7 had been used by several workers to define crop opportunities (Virmani, 1975; Reddy et al, 1977). This criteria was also been used very successfully by Biswas and Sarker (1978) to map the DPAM. They defined the 'Optimal Moisture Availability Index' (OMAI) using the rainfall received 50 per cent of the time (calculated by the gamma function). They then calculated the number of weeks where the OMAI exceeded 0.3 and 0.7 for all Maharashtra stations, and developed the following spatial classification:

<u>Zone</u>	<u>Number of weeks with OMAI of at least</u>	
	<u>0.3</u>	<u>0.7</u>
D	<10	<1
E	10	1
F	11	4
G	14	7

In the map produced, the boundary of Zone F coincided almost exactly with the administrative boundary of the Drought Prone Area, with only slight boundary differences

⁷ Hargreaves worked on agroclimatology in Latin America. This shows how ideas moved between continents within one scientific specialty (see Hargreaves, 1967).

(see Fig 3.7). Clearly the OMAI could be a very useful and simple technique for mapping cropping seasons and thus production options, although it was still more useful for rainy season (kharif) crops. In fact the OMAI method became a standard for IMD, and was later applied in other states. However it still gave fewer divisions for forecasting than the map developed in my study (see Fig 3.1), based on my own studies of dry spells crop associations and P:PET study outlined below.

3.4.3 My own study of probabilities for a 'growing season'

The work of Srinivas Murthy (1976) was thus one of the only pieces of agrometeorological work in IMD which actually expanded into reasons for the vulnerability of dryland crops. I therefore decided to expand this kind of work in my study, to show what information could be generated by using these simpler techniques. The seven stations of Malegaon, Aurangabad, Ahmednagar, Sholapur, Jalgaon, Poona and Akola were chosen as stations for which both rainfall and monthly PET averages were available (1901-1976). Of these, the first four were DPA stations, Malegaon and Aurangabad being in the northern DPA. Poona station, while close to the boundary, is not strictly in the DPAM. A programme was written to calculate the ratio of actual monthly rainfall to average monthly PET for all months 1901-1976. Humid and moist months (ratio >0.5) were distinguished from moderately dry and dry months (ratio <0.5). A number of criteria were then developed to monitor different kinds of kharif and rabi risks, and thus to establish the overall level of drought risks and spells of drought years (see Appendix 3). It was not possible to report all the results of that study in this chapter. However, several tables are reproduced now to show the usefulness of the technique for demonstrating constraints on production. These showed, firstly, how expectations of consecutive months of 'humid' and 'moist' months influenced the choice

of crops. Secondly, the technique could be used to compile types of risk, into a composite picture of risks of crop failure. Thirdly tables show how both can be combined into a crop decision matrix for farmers (see next section).

Table 3.5a summarises the production alternatives by looking at the incidence of consecutive growing months (months in the humid or moist categories). The chance of at least three months consecutive growing period brought out the extremely risky nature of kharif cropping at Malegaon and Ahmednagar, with 'good years' on average only 1 in 3 years at Malegaon, and even less at Ahmednagar.

Table 3.5 Growth months (moist or humid) across the monsoon period

(a) % of years with at least 3,4, or 5 consecutive growing months (for kharif crop or double cropping).

	<u>3</u>	At least <u>4</u>	<u>5 months</u>
Malegaon	36.8	21.0	2.6
Ahmednagar	28.9	22.3	9.2
Sholapur	52.6	36.8	14.5
Aurangabad	68.4	48.7	15.8
Poona	64.4	39.5	22.3
Jalgaon	80.3	48.7	13.1
Akola	78.9	44.7	13.1

(b) % of years with two consecutive growth months in September and October for a fair rabi crop.

Malegaon	27.3
Ahmednagar	35.5
Sholapur	34.2
Aurangabad	25.0
Poona	38.1
Jalgaon	18.4
Akola	22.4

Yet farmers with shallow soils in these areas had no alternative but to grow kharif crops. Conversely, the chance of at least three months growing period was higher at other stations, particularly the non-Drought Prone Area stations of Jalgaon and Akola. The chance was also unexpectedly high (just over 50 per cent) at Sholapur, and thus good for catchcropping a short duration kharif crop before rabi.

The chance of at least four consecutive months represented the chance to grow longer duration kharif crops such as kharif sorghum or cotton. Such a chance only materialised on average 1 year in 5 at Malegaon and Ahmednagar. Chances were substantially greater at Aurangabad, Jalgaon and Akola, which were important cotton or kharif sorghum producers. Cotton and sorghum of course brought substantially greater profits than the millets and pulse crops feasible with only three consecutive months.

It was the percentage frequency of at least five months which showed the real potential of double cropping. This was not particularly high at any site, although it reached over 15 per cent at Aurangabad and Poona. The problems and costs of double cropping at this level of risk were quite high, and farmers might have preferred the income or subsistence value of a more reliable 4-month kharif crop like cotton or sorghum. Many farmers might also be 'catch cropping' a second crop at this level of frequency, without formal guidance.

To demonstrate this decision problem of kharif versus rabi cropping further, Table 3.5b also shows the chance of getting a reasonable rabi crop. It was highest, as expected, at Ahmednagar, Sholapur and Poona, where farmers with deeper soils could obtain fair yields. At other sites, however, the chances were less than 30 per cent, and substantially lower than the chance of at least four kharif months. This again confirmed that at these sites farmers could be more disposed towards a single kharif crop. Indeed, as they crop across the period July-October, they may not distinguish kharif and rabi options that specifically. Looking again at Table 3.4 in terms of consecutive cropping months, all sites, except for Ahmednagar, were more reliable for a three-month short duration kharif crop than a rabi crop. Even Sholapur, a traditional rabi district, had 52 per cent of years with at least three months in kharif, as against only 34 per cent of years with good rabi rains.

Sholapur and Poona had about the same chance for at least four consecutive kharif months, as a good rabi crop, but several other features might be responsible for the actual rabi preference. It will be shown in Table 3.6 that there was a stronger risk of a sequence

of poor kharif years than of poor rabi years, especially for farmers on deeper soils. Also there remained resistance to working the deep black soils in the wet kharif period, and a dietary preference for the grain produced by rabi sorghum varieties. Thus at Sholapur, Poona, Ahmednagar, and also the deeper black soils of Aurangabad soils, one could expect a preference for rabi crops, regardless of the 'average frequency' of rabi drought. All these sites, except Ahmednagar, however, could have reaped benefits from more concerted efforts to 'catch crop' a short duration crop in kharif.

At all other sites, and on shallow soils at all sites, the preference might be for kharif crops, and there was limited potential for catching a second crop. On shallow soils, and less favourable sites like Malegaon, only 3 month kharif crops could have a reasonable chance of success: there appeared almost no scope for double cropping. At the other sites, Jalgaon, Akola and Aurangabad, the chance of double cropping also materialised as limited, but the chance of 4 kharif months was good. The cash return of a cotton crop, or subsistence value of sorghum, could make it more sensible to concentrate on a single kharif crop, than to chance a lower value double crop of millet and pulses.

3.4.4 My own studies of P:PET ratios and specific drought risks

I also undertook a detailed analysis into how P:PET ratios could be used to study specific drought risks. Full details of criteria are given in Appendix 3, but briefly these are:

1. Late onset was indicated if the first ratio of 0.5 or more did not occur until August or later;
2. Dry spells were studied through the incidence and consecutive occurrence of months with a ratio of less than 0.5;

3. The risks for rabi crops were studied through the indicator value in September and October. A ratio of less than 0.5 delayed planting. A ratio of 0.5 or more in only one of these months was likely to cause depressed yields on all but the deepest soils: failure to receive a ratio value of 0.5 or above in either month would result in rabi failure on all soils.

General frequencies of drought risks to production

The combined results are shown in Table 3.6 below, which shows the risks of total failure and depressed yields as modelled from monthly data series 1901-1976. In kharif, total failure was considered to result from: failure of onset; late onset in August or after; or if there are two or more months with a ratio less than 0.5 in succession. General depressed yields would result if there was one dry or moderately dry month (ratio less than 0.5). In rabi, total failure was considered to result if there is no ratio above 0.5 in September or October. General depressed yields were likely if only one month with a ratio of 0.5 or above was received. The risks from a dry September were not included in the analysis, because they are influenced by other features like temperature. The kharif risks given in earlier Table 3.4 also showed these 'core' Drought Prone Area stations of Malegaon, Ahmednagar and Sholapur.

Planting after mid-September meant that the cold weather of December was more likely to promote unwanted tillering of sorghum. The study showed a risk of a dry or moderately dry September at around 10% in Malegaon, Ahmednagar and Sholapur, rising to 31.1% in Poona. This risk was not that substantial, although for deep soils it was equal to that of failure of the rains. More research was still to be done in 1978 on the effects of low temperature on sorghum yields, however, before its importance relative to soil moisture stress could be evaluated.

Table 3.6 Summary of kharif and rabi risks, % years

	Total kharif failure	General depressed yields	Total kharif risks
Malegaon	22.4	43.4	65.8
Ahmednagar	22.4	50.0	72.4
Sholapur	21.0	23.7	44.7
Aurangabad	2.6	21.0	23.7
Poona	6.5	18.4	29.9
Jalgaon	1.3	13.1	14.4
Akola	2.6	13.1	15.7

	Total rabi failure	General depressed yields	Total rabi risks
Malegaon	19.5	59.7	79.2
Ahmednagar	7.8	54.5	62.3
Sholapur	7.8	53.2	61.0
Aurangabad	11.7	62.3	72.7
Poona	11.7	40.3	51.9
Jalgaon	25.0	59.7	84.4
Akola	17.1	55.8	72.7

All these stations shared a probable risk of total crop failure of 20 per cent over the long-term, and at Ahmednagar and Sholapur the risk of depressed yields was a further 40-50 per cent. The kharif risks of depressed yields at Sholapur were less high, confirming my idea that when kharif rains did establish themselves over Sholapur, they could be good, so there was some scope for increased kharif cropping in Sholapur district. If one looked at total kharif risks, however, at these three stations, they appeared far more risky and 'droughtprone' than the remaining stations. The position of Aurangabad was interesting - it had a very low risk of total kharif failure, lower indeed than Poona (not in the Drought Prone Area), but its risks of general depressed yields is over 20 per cent and similar to that of Sholapur. Aurangabad also had less favourable rabi cropping opportunities than Poona. The other two stations, Jalgaon and Akola, could have general kharif risks at the rather low level of 15 per cent; that was still over one year in ten, but clearly lower than Drought Prone Area stations.

Rabi risks were extremely interesting, the risks of absolute failure appearing quite different from those of depressed yields. In this analytical approach, at Sholapur and Ahmednagar these risks of total failure fell as low as 8%. The risks at Malegaon, Jalgaon and Akola were substantially greater, again confirming that these would be kharif crop sites. However risks of depressed yields appeared alarmingly high at all sites. As discussed earlier, sites such as Aurangabad, Jalgaon and Akola had good kharif options, as medium soils could be put under cotton, kharif sorghum or shorter duration kharif crops.

Total failure in rabi appeared less than the risk of total failure in kharif only at Ahmednagar and Sholapur, where indeed it was substantially lower. The risks of general depressed yields, however, were higher than kharif crops at all sites. In total rabi risks, only at Ahmednagar did rabi cropping have a clear advantage over kharif cropping. It seemed that most soils at Sholapur could take up kharif cropping with some advantages, in the ways already discussed by the research station. At Ahmednagar, however, the risks to such soils were about the same in rabi as with kharif crops, and for subsistence needs farmers might opt for rabi sorghum. Thus the drought risk structure at Ahmednagar, substantial for kharif and rabi, might have little potential to change under any of the cropping strategies then being promoted.

Sequences of good and bad years

The vulnerability of a farmer to drought, and his individual 'drought-proneness', depends on his ability in the face of three dynamics. Two of these, the general frequency of low yields and the frequency of good years, have already been discussed. The third factor is the incidence of sequences of bad years. Using the data from previous tables, the length of sequences of years of depressed yields and scarcity (i.e. all risks) are shown in Table 3.7.

For kharif yields, Malegaon, Ahmednagar and Sholapur had all experienced about ten sequences of at least two years of depressed yields in the period 1900-1976.

Table 3.7 Number of sequences of at least 1...14 years of:

(a) depressed yields kharif crop

Runs of years/ Rainfall station	1	2	3	4	5	6	7	8	9	10	11	12	13	14	>14
Malegaon	19	11	8	6	4	2									
Ahmednagar	19	10	7	4	2	1	1	1	1	1	1	1	1	1	1
Sholapur	17	11	4	1	1	1	1								
Aurangabad	14	3	1	1											
Pune	16	7	1	1											
Jalgaon	17	4													
Akola	11	3	1												

(b) depressed yields: rabi crop

Rainfall station/ Years	1	2	3	4	5	6	7	8	9	10	11	12	13	14	>14
Malegaon	19	11	8	7	5	3	2	1	1	1	1	1	1	1	1
Ahmednagar	19	11	8	7	5	3	2	1	1	1	1	1	1	1	
Sholapur	19	9		2	2	2	1	1	1						
Aurangabad	14	8	6	6	4	4	4	3	3	2	1	1	1		
Pune	12	7	5	4	3	2	2	1							
Jalgaon	12	11	9	6	4	3	3	3	3	3	3	2			
Akola	14	10	8	7	6	2									

(c) Total failure rabi crop

Rainfall station/ Years	1	2	3	4	5	6	7	8	9	10	11	12	13	14	>14
Malegaon	13	2													
Ahmednagar	7														
Sholapur	6														
Aurangabad	9	2													
Pune	8	1													
Jalgaon	13	4													
Akola	7	1													

(using rainfall records 1901-1976)

For Malegaon and Ahmednagar around five of these sequences stretched for four consecutive years. Sholapur shows a lower risk of these very long sequences. This is one reason why, of course, subsistence farmers on deeper soils at Sholapur and Ahmednagar might opt for rabi crops. Farmers on shallow soils, and virtually all farmers at Malegaon,

had no way of avoiding these sequences, with their highly debilitating effects on the local economy. For other stations in kharif, while they did have these occurrences of bad years, they only rarely persisted for a second year.

Clearly the kharif farmers at Malegaon, Ahmednagar and Sholapur inhabited a highly risky production environment. However, the position for depressed yields with rabi crops was almost as bad at the three 'core' stations of Malegaon, Ahmednagar and Sholapur. Malegaon and Ahmednagar again showed five occasions when a sequence of depressed yields of at least five years occurred and again Sholapur showed a slightly lower risk of these prolonged spells.

Risks of long sequences were also high at the other stations for rabi crops, again suggesting that at the stations with more favourable kharif opportunities, kharif crops would predominate. For total failure of rabi crops, however, consecutive years were much less frequent. At Ahmednagar and Sholapur, there were no cases of two consecutive years with low ratios in both September and October.

P:PET ratios and crop decision matrices

It then became possible to set up a crop decision matrix for a farmer at a site, depending on whether they occupied shallow, medium or deep soils. From this one could also assess current vulnerability to drought risk, and the real scope for a reduction in drought proneness by new farming practices being promoted by research stations. Individual examples are given in Tables 3.8i-iii. for Sholapur, Ahmednagar and Malegaon. The actual cropping patterns found in these districts confirmed the crops suggested by these decision matrices. This indicated that farmers were managing their own monitoring and adapting to new options and conditions. Statistical analysis did not identify much that they were not aware of - rather it confirmed their responsiveness.

If one looked at these matrices in relation to current development strategies then being promoted, the opportunities to reduce drought proneness were not very encouraging. One extremely important point was that vulnerable northern Drought Prone Area sites, of which Malegaon in Nasik district was a prime example, was not represented by any current research station. Akola, while it also had a kharif maximum, had a good chance of a four month kharif cropping period (sorghum or cotton) and so quite a different risk structure. Secondly, at Malegaon generally, and on shallow soils at Ahmednagar and Sholapur, there were few strategies which could really reduce the risks posed by dry spells. Thus more attention should have been given to shallow soils than had been given to date by any research station in 1978. Even ICRISAT had done little work on alfisols of less than 50cm depth at that time.

These models also suggested that there might be some new kharif farming opportunities to examine at Sholapur. Table 3.4 showed that Sholapur had a 53 per cent and 37 per cent chance respectively of either three or four months of rain in kharif. The 'four month' kharif chance could have made it worth investigating the kharif sorghum/tur strategy being promoted by ICRISAT. Also, if very short duration pulses were raised, farmers would still have the opportunity to sow rabi crops. The options for change at Ahmednagar were much less favourable, having only a 29 per cent chance of three consecutive kharif months. This was a high level of risk for the adoption of kharif crops, so farmers seemed likely to remain with a very strong rabi emphasis, only 'catch cropping' a short duration pulse crop in favourable years before the rabi crop. Because of the high risk of failure or such a kharif crop (three years in four) farmers probably needed special encouragement to adopt the strategy. These results for Ahmednagar probably represented a broad zone extending from Ahmednagar district into eastern Poona and western Sholapur.

Table 3.8i Crop decision matrix:Sholapur

Sholapur	Soils		
	Shallow	Medium	Deep
General drought risks lower in kharif than rabi?	K H	Yes	No
Chance of a good three month kharif crop greater than a fair rabi crop?	A R I	Yes	No
Chance of a good four month kharif crop greater than a fair rabi crop?	F	Almost the same	
Chance of a sequence of at least two years of depressed yields lower in kharif than rabi?	O N L Y	Almost the same	No

Conclusions: Farmers on shallow soils will cultivate short duration kharif crops (general risk level 45 per cent). Farmers on medium soils probably cultivate rabi sorghum for subsistence (dietary preference, difficulties in working soil in kharif, sequences of bad years the same) (general drought risk 61 per cent). Other farmers cultivate rabi crops.

Actual current cropping pattern - 72 per cent under rabi crops, no kharif sorghum, reflects this choice.

Crop options to reduce drought proneness - Very few on shallow soils. Scope to transfer to short and medium duration kharif crops on medium soils provided economic and subsistence results compare with current rabi crops, and problems in working soils can be met. Otherwise, apparent drought risk may be lessened (from 61% to 45%) but food problems unchanged.

Table 3.8ii Crop decision matrix: Ahmednagar

Ahmednagar	Soils		
	Shallow	Medium	Deep
General drought risks are lower in kharif than rabi?	K H	No	No
Chance of a good three month rabi crop greater than a fair rabi crop?	A R I F	No	No
Chance of a good four month kharif crop greater than a fair rabi crop?	O N L Y	No	No
Chance of a sequence of at least two years of depressed yields lower in kharif than rabi?		Same	No

Conclusions : Farmers on shallow soils will cultivate short duration kharif crops (general drought risk 72 per cent). All other farmers will cultivate rabi crops (general drought risk for medium soils 62.2 per cent of years, only 7.8 per cent of deep soils).

Actual current cropping pattern - 69 per cent rabi crops, 24 per cent kharif crops, but no kharif sorghum, reflects this position.

Crop options to reduce drought proneness - Very few for shallow soils. Promote catch cropping of kharif pulses on other soils, although double cropping only successful one year in ten, so contribution to profits limited. Still better to concentrate on rabi production.

Table 3.8iii Crop decision matrix : Malegaon

Malegaon	Soils		
	Shallow	Medium	Deep
General drought risks lower in kharif than rabi?	K H	Yes	No
Chance of a good three month kharif crop greater than a fair rabi crop?	A R	Yes	Yes
Chance of a good four month kharif crop greater than a fair rabi crop?	I F	No	No
Chance of a sequence of at least two years of depressed yields lower in kharif than rabi?	O N L Y	Same	No

Conclusions: Farmers on shallow soils grow short duration kharif crops (general drought risk 66 per cent). Farmers on medium deep soils also grow short duration kharif crops, as overall economic risks are less. Other farmers may grow rabi crops (general drought risks 20 per cent). Actual current cropping pattern - kharif crops 76 per cent (millet 50 per cent, kharif sorghum 6 per cent) reflects this choice.

Crop options to reduce drought proneness - very few indeed, economic position made worse by dependence on low value kharif crop.

3.5 CONCLUSIONS

This chapter began with a list of six development needs for which information could have been generated by agencies with a mission in meteorology and agriculture. By 1978, criteria had been generated that mapped the DPA in ways comparative to scarcity models already used by the state, but made little detailed differentiation of local conditions to help design development programmes. The weather patterns causing difficulties in one monsoon season were quite well understood, and some more detailed spatial differentiation across the DPAM had started with criteria using dryspell analysis and P:PET ratios. However, no modelling was done on the build-up of inter-year runs of bad seasons for farmers. Generally speaking, there was little advantage of more complex modelling over simple procedures, and field-based observations of locally specific criteria gave the best – and only really reliable - information. This called into question the idea of

seeking generically appropriate criteria and models for analysing the problems of agricultural drought. In general little progress had been made for

- signal criteria on which to alert authorities on impending food scarcity conditions
- social rather than environmental factors relevant to change or stagnation in local farming practices
- appropriate short term relief measures.

Despite the wealth of information that could have been monitored to understand drought and drought-proneness, most actual attention remained with rainfall, basic meteorological measurements for evapotranspiration calculations, crop yields at research stations, and crop returns reported from village authorities for the agricultural census of each year. Perhaps, however, this old *annewari* assessment tool, which had real political embeddedness around which a variety of local governance actors could lobby, respond and broker action, was still a more relevant tool for action than detailed meteorological criteria from research that may not have been that valued or understood by local development agencies.

Both cognitive and social institutionalisation can help explain these weaknesses. This study suggests that both IMD and ICAR had high cognitive and social institutionalisation, in that they followed agreed methodologies and targets, and produced new information relevant to their own norms and objectives rather than external ones. Both tended to focus on research related to agricultural planning and aberrant weather conditions, rather than on criteria to assist wider development needs in assessing drought-proneness. The reliability of own data and tested statistical methods remained their framing objects. At best, they had looked at scarcity on an areal perspective – and did not relate their work to the ‘drought-proneness’ of individual farmers. Neither had admitted wider agro-economic or sociological data into their analysis at that time, not even to look at the classic known problem of spells of bad

years. ICRISAT did try to push new research into which it tried to invite IMD and ICAR, and certainly ICRISAT in the late 1970's benefited from some of their data. But no major new scientific findings or cognition in meteorology emerged at a level that could become embedded and used in the public agencies for development. Once the energetic staff of that time moved on, the coalition platform on drought and vulnerability fell away.

The relative isolation of meteorological research is another answer, where there had been relatively little inter-disciplinary contact with socio-economic research. While scientists in specialty agencies also frequently took up new models and criteria generated by other scientists to test on local conditions, they rarely set out to look at highly localised problems. The complexity of agriculture practised by the small farmer was another reason, as it was less amenable to easy statistical analysis and demanded regular contact with farmers in order to build up data sets. The greatest reason, however, I thought, was that research workers faced problems in seeing value in production systems that most of them were taught to see as inferior and were working to eliminate. Greater attention to modelling the problems of the small farmers could come only with recognition that that farming sector would not only survive, but also contribute to the food production of the country.

The search to replace socio-economic criteria for boundary and mapping needs, by generic 'scientific' methods to identify potential crop production periods was however relatively successful in terms of IMD's norms and 'guidelines'- and the OMAI index moved into the repertoire of India-wide techniques used by IMD. The OMAI index did become used more widely in some (re)mapping of boundary areas of droughtprone areas, and did become an influence on the localised weather forecasting zones that emerged more in the 1980's. BCBiswas later became Director of IMD-Poona, as appropriate to his

scientific successes and very genuine meteorological enthusiasm. However my dryspell studies and suggestions for six crop-weather zones with different crop associations stayed as maps in a report.

Both my own work, and that of other agro-meteorologists then, overwhelming fulfilled the assertion that a scientific approach was a search for patterns (Nightingale, 1999). Computers gave us endless opportunities to model and statistically analyse data. We still worked with the belief that good statistics could almost represent scientific facts, and this science could be a source of tools and techniques to help design, or set up more efficient strategies of applied research and development in the DPAM (after Brooks, 1994). The main perspectives I worked to add alongside work being done by others was to look at frequencies and not only average lengths of dry spells, but also runs of bad years assessed through P:PET ratios, thinking these were critically important for small farmers. What I learned once I collected production data was that farmers had already spotted these patterns and were relating options to them. I learned that farmers never wait from recommendations or the 'approval' of statistics, but will be experimenting immediately from their own cognitive assessments. My faith in models and modelling was also shattered as I learned just how easily bad programming happened and how unrepresentative and unreliable model cobbled up from surrogate and generalised figures could be. My own interests in interdisciplinary studies and syntheses increased – but only as they could be based in good field data. While I communicated my reports back to IMD, none of my insights got taken up in subsequent work. However, I also have to acknowledge that I did not stay in these same networks of scientists to try and disseminate or 'institutionalise' my own findings. Thus I also had a first lesson in the limited power of experts if they do not integrate with their own network of practitioners. In this case, my network became those mobile in development-oriented research, not those institutionalised into specialty organisations.

The agro-meteorology of the droughtprone area of 1978 was still really the meteorology of important cash crops often discussed on a regional basis. The key emphasis in research reflected theoretical production potential, and the constraints weather gave to this, without reference to the real vulnerability that typified dryland farming systems or drought-prone locations at that time. Thus the 'useful' contribution of agrometeorology was really only benefiting the farmers with substantial resources who might be able to withstand drought periods. A real focus of droughtproneness, and the vulnerability this caused for small farmers remained lacking, or at least just left with the older *annewari* approach of crop yields used since the turn of the century. In 1982, a Taskforce reviewed the achievements and areal coverage of the DPAP and was sharply critical of the agro-meteorological data made available by states. They commented (Government of India, 1982, p.5)

..."In most cases the data received are too general to permit any worthwhile analysis. The paucity of microlevel data indicates that, over the years, a basis for crop planning in areas deficient in water has still not been evolved, and the use of meteorological information for scientific agriculture is still minimal".

CHAPTER 4

GROUNDWATER DEVELOPMENT IN RAYALASEEMA: FIRST STEPS IN EXACERBATING GROUNDWATER DROUGHT

...In view of past experience, the proposal to pump... crores for works in the rural areas evokes the grave anxiety that if the quality of a large number of works is as bad as it has been, and the leakage of funds, due to corruption, is as bad as it has been, there may be neither a substantial addition to productive capacity nor a significant income transfer to show for this enormous outlay. Instead of reducing the poverty and idleness of the poorest, it may further enrich the rural oligarch and bureaucracy, and increase inequity and tension in the countryside." Krishna, 1974

4.1. INTRODUCTION

This chapter explores dugwell and borewell expansion in the droughtprone Rayalaseema region of Andhra Pradesh, as it was occurring in 1984, in the ‘first phase’ of groundwater development – popularisation of technology (Burke and Moench 2000). It studies the agencies emerging to support technology dissemination and their cognitive and technical norms, contributing to research sub-questions 1, 2, and 4 for groundwater drought. It shows that operational rather than ‘scientific’ criteria evolved around the easily measurable criteria like water levels and pumping yields, and that virtually no norms showed any special consideration of drought – either in how lower rainfall affected recharge or on falling water levels that could restrict intensity of cropping.

In common with the Indian planning approach (see Intermezzo 1), agencies were again created both as a source of techniques for more ‘efficient’ design and to provide a knowledge base for more efficient development strategies for technologies. However, this chapter introduces some different kinds of agencies and institutionalised actors into the development arena of a droughtprone area – newly formed ‘scientific’ resource assessment agencies (the groundwater departments) and specialised technology dissemination agencies for borewell development (irrigation development corporations). Both show very different problems and struggles to reach the confident institutionalisation visible with the IMD and ICAR in the last chapter. The chapter shows how much of the

scale and spatial diversity in groundwater development, and over-extraction of groundwater, was driven by technoeconomic networks – associations of banks, credit/subsidy institutions and technology installation agencies rather than any well-established technoscientific specialty agencies. Thus looking into droughtprone areas through groundwater mechanisms, rather than rainfall, configures different actors and norms in this development arena, and the actors and framing objects shaping the cognitive space of a droughtprone area.

My own work became directed into a critical evaluation of these early cognitive and technical norms in these agencies involved in groundwater development. In this chapter, as in Chapter 3, I both critique and try to expand these generic norms and models created, again to show better the risks to small farmers of groundwater development otherwise invisible in the standardised approaches of many of the general assessment criteria. I also review the biased choices and corruption that spread into groundwater development by wells, feasible because of the kind of techno-economic networks present. In this respect, the study shows how little science really contributed to conscientious public action in this complex technological context. Technology was driving what science evolved in the groundwater field, both as it yielded more information, but also in how it structured analytical frameworks on potential well numbers, and eventually triggered questions about its social and environmental impact.

I came to this research programme to work more in irrigation development realities in a DPA, after this frustration with the separateness of agro-meteorology from farmer realities. I also came with the invitation of the state irrigation development corporation (APSIDC), all set to work with these important technoscientific agencies (with many people who also gave me a lot of support). No one prepared me, however, for the scale of financial irregularities on the ground. This ultimately drove a more critical investigation of the techno-economic networks actually at work.

After an overview of hydrogeology in section 4.2, section 4.3 examines key scientific and technical norms used in groundwater development, with particular reference to selection of dug-or borewell technology, and the risk environment of small farmers taking up new credit programmes. Very simple additional calculations could have indicated serious potential risks in operations and profitability for small farmers. Failure to perform these is attributed to the pressure to disburse funds under development programmes. Section 4.4 reviews the agencies involved in these programmes and techno-economic networks, which allowed these simplistic planning methods to steamroller ahead. Sections 4.5 and 4.6 look at the outcomes of agency action in borewell and dug-wells respectively, especially the corruption that emerged - and whether science made any real difference in local action, given incentives and pressures to disburse subsidies and credit. Initial sections discuss the Rayalaseema region: later sections focus into Kurnool district and Dhone taluk¹. The corruption uncovered in Dhone made work very difficult. Moving between different districts helped me to see what procedures should be in place and what questions to ask.

4.2 AGROECOLOGY, HYDROGEOLOGY AND GROUNDWATER MOBILISATION

4.2.1 The Rayalaseema region

The Rayalaseema region consists of four districts (Kurnool Anantapur, Cuddapah and Chittoor) that form the core droughtprone region of Andhra Pradesh. The region has an average annual rainfall of less than 900mm, and Kurnool and Anantapur have less than 700mm. This 700mm isohyet was used to define the 'Drought Prone Area Programme' in

¹ A taluk or block is the first administrative subdivision of a district. In Andhra Pradesh, these were later subdivided into mandals, which have around 5 villages in them.

Andhra Pradesh State, alongside low levels of irrigation (see India Meteorological Department, 1972; Revenue Department, 1981). A more detailed picture of crop risk was developed through mapping 'agroclimatic zones' defined by the number of consecutive weeks of moisture availability - the OMAI described in the previous chapter - shown in Figure 4.1 (Mandal et al, 1983). Lower rainfall also limited the recharge available for groundwater. Drought-proneness was further exacerbated by the soil type present². The two important river systems for the region are the Tungabhadra river, a tributary of the Krishna system, and the Pennar river: these support several large surface irrigation and small lift irrigation systems. (Groundwater Department, 1976, and 1976/1995)

The geology of Rayalaseema divides into three systems: a map is given in Appendix 4. The oldest series is the crystalline 'Archean' rocks composed of granites, gneisses and schists, where groundwater availability is linked to the existence of joints and fractures in the rocks, to contact planes with dykes, or to the weathered zone, usually up to 30 metres deep. The second series is the sedimentary Cuddapah-Kurnool formation, including sandstones, limestones and shales. The third and most recent are alluvial sands, clays and gravels found in river valley areas. The first two of these systems are together classified as 'hard rocks' for development purposes. Groundwater resources are generally poor in these hard rocks, with slow rates of water movement, typically 1-10m³/day/m². The degree of fracturing and depth of the weathered zone varies greatly across the area, as does the level of recharge and depth to the water table, making localised groundwater potential groundwater very variable. Proximity to major irrigation schemes as in

² 'Red' soils are shallow (less than 50mm), sandy and gravelly soils developed over the granite rocks: they are low in nutrients, but with good management can support a wide variety of 'irrigated dry' crops, and the high value tree crops like citrus and mulberry. Very poor skeletal hill soils are best developed under forestry. The black soils are clay loams often over 1.5 metres deep and have better nutrient availability and moisture holding capacity, but may become waterlogged when wet and crack when dry. (source: Interview with GWSG Branch office, Kurnool district, July, 1983; Groundwater Department, 1976).

northwest Kurnool district) also influences recharge levels. (Hanamantha Rao, 1982; Groundwater Department, 1976 and 1976/1991)

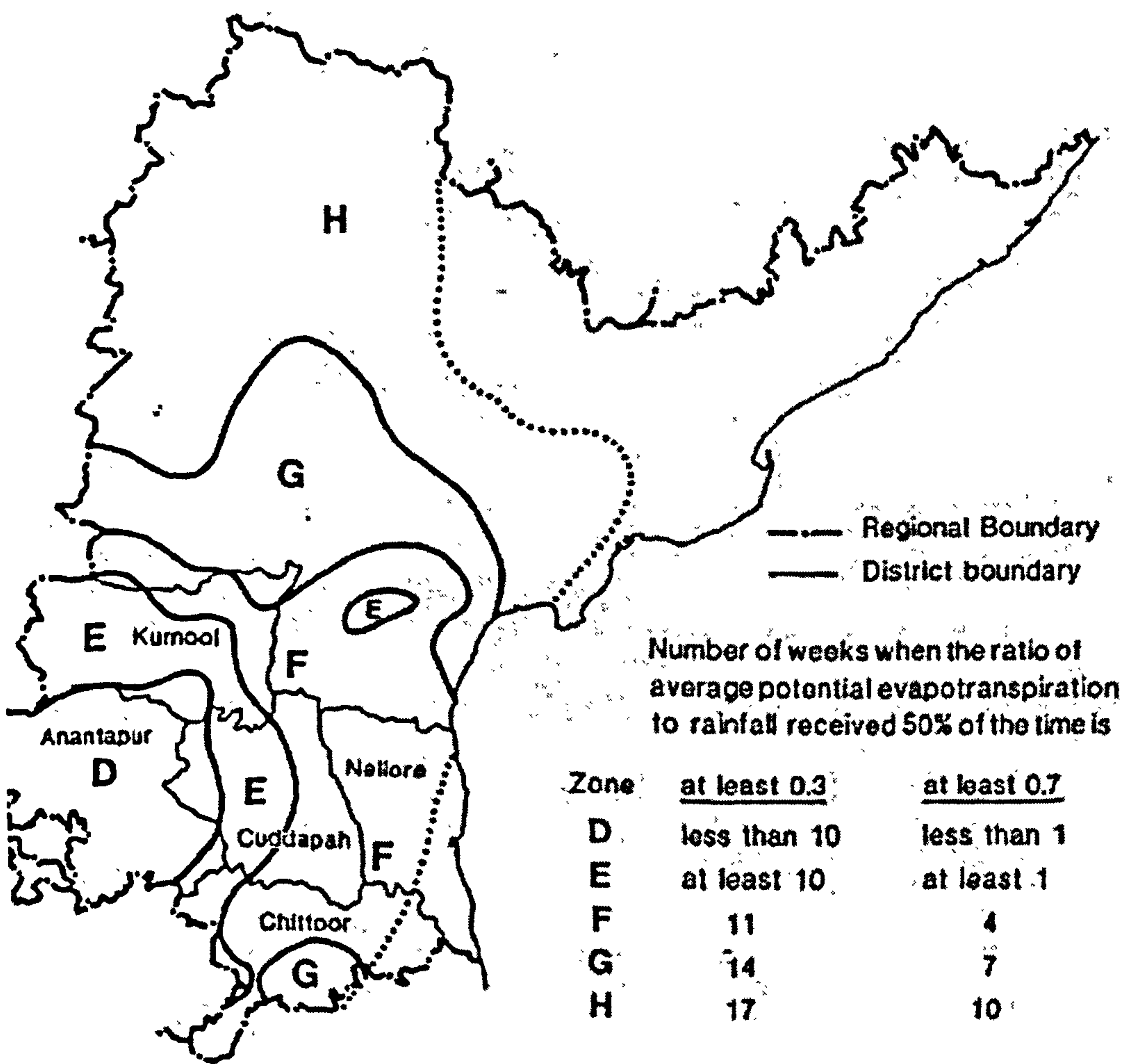


Fig 4.1 Moisture availability zones and district boundaries, Rayalaseema region (Compiled from India Meteorological Department, 1973; Khambete et. al., 1983)

Zones are defined according to the Moisture Availability Index

Zone D defines the least favourable production zone, with survival conditions operating for less than 10 weeks in 50% of years. Anantapur district largely falls under this zone.

Zone E, where survival conditions are a little more secure, covers western and southern Kurnool district.

Zone F, covering eastern Kurnool district, western Cuddapah and a small part of Chittoor, has both a more substantial survival period and several weeks of good rainfall within this, in 50% of years.

Table 4.1 Groundwater parameters influencing dug well development (source Groundwater Department 1981, 1976; Hanamantha Rao, 1982; own calculations)

Rock type	Specific capacity l/min/m ²	Time to recharge well level to previous level (days)		Depth to watertable (m)	Range of water table fluctuations (m)		Water quality problems
		10 m diam.	15 m diam		Av.	Max.	
<u>Crystalline rocks</u>	30-130	5 - 1	12 - 1	1 15	2.3	5.3	Severe in black soil areas
<u>Shales</u>							
<i>Auk and Nandyal</i>	20-80	6 - 1	14 - 3.5)))	4 - 16	4.7	9.3	(Severe in some (sites due to parent (materials (
<i>Tadipatri</i>	268	0.5	1)				
<u>Limestones</u>				2 - 10			
<i>Narji</i>	129-935	1-0.13	2 - 0.3))		2.7	3.2	None
<i>Koilkuntla</i>	60-300	2-0.4	4.7 - 0.9))				Several in black soil areas
<i>Vempalle</i>	20	6.3	14')				None
<u>Quartzites</u>	50-300	2.5-0.4	5.6 - 9	No data	2.3	4.8	None
<u>Alluvial Infill</u>	200	0.6	1.6	1.8	1.8	3.2	None

Table 4.1 shows groundwater and well behaviour characteristics for these rock types. Dug wells (open wells) were the traditional technology of the region, with a water-lifting device operated by oxen (a *mhot*). They were large, typically 10-15 metres in diameter and up to 10-12 metres deep, providing reservoir storage against slow permeability and recharge rate.

Table 4.2 shows the state of groundwater development in 1982, when only 9% of the groundwater resources of Kurnool district were registered as developed – a startlingly low figure given concerns about rapid development elsewhere. Explanations for this included higher levels of canal irrigation and problem geology and soils, and lack of programmes for borewell technology at this time. Higher well numbers in other districts reflected older traditions of well use, and special development programmes in districts like Anantapur. (Interviews, Groundwater Department Branch Officers, Kurnool and Anantapur districts, July and August 1983.)

Table 4.2 Groundwater potential in Rayalaseema districts 1982

Rayalaseema District	Status of groundwater potential development (%)	Number of new pumpsets feasible	% Gross irrigable area under dugwells	% Gross irrigable area under tubewells
Kurnool	9.31	61404	58.2	-
Anantapur	32.8	24637	78.5	0.04
Cuddapah	58.1	14206	81.2	1.9
Chittoor	30.4	21979	75.7	1.1

Source: Hanumantha Rao, (1982).

4.2.2 The real costs of dugwells

Excavating a dugwell involved several elements which came to have standardised costings in their development programmes (Hanumantha Rao, 1982; n.d.)

- digging of 'trial pit' to ensure water is available
- excavation work

- costs of explosives and drills for breaking rocks
- availability of pump for dewatering
- lining (lining) of a well to prevent its collapse
- installation of pump and pumphouse
- subsequent development of canals for distributing water.

The two elements that crucially influenced the cost of a dug well were depth, and whether blasting was necessary – this could raise prices prohibitively³. Even in rocks relatively easy to excavate, a 10 metre depth cost about 10,000 rupees without lining – but in such unconsolidated rocks, lining was necessary against siltation and collapse of a well. However, lining the full well depth almost doubled the cost. Only with a well of 8 metres depth or less, was it possible to excavate and line a well at less than 10-11,000 rupees at this time. In 1983 there were references of 'up to 50,000 rupees' as the cost of a deep hand-dug well. The costs were complicated by difficulties in obtaining explosives, and organising the labour involved. Typically it could take 15 adults five-six months to excavate a well, with work often spread over 18 months so that fluctuations in water table could be monitored.

It was against this high cost that in-well-bore technology arose, available through both the State agency APSCRIC, and private contractors. An in-well-bore cost only about 75-150 rupees per metre in 1983 (the sanctioned agency figure was noted as 140 rupees in APSCRIC, 1981). It was a measure of the burgeoning possibilities of this technology at this time, that Anantapur district had around 100 contractors for undertaking in-well-bore work, compared with around 12 contractors for tubewell work (Interview, Groundwater Department, Branch Officer Kumool District, July 1983). With this technology, water was pumped via an in-well bore (drilled at first only to

³ Blasting could increase cost per volume up to six times, and brought work supervision problems. For examples of standard costings see Appendix 4.

25m) into the well, and thence to the surrounding area. Except in weathered zones prone to collapse, in-well-bore technology was very feasible – but its expansion could mine the groundwater table.

4.2.3 Borewells

In the hard rocks, the borewells first developed were typically 50m in depth and cased only in the weathered zone i.e. about the top six metres. Full casing was too expensive, with a cost of around 220,000 rupees. General costings of borewell elements at 1983 prices were (derived from APSIDC, 1980, 1983):

borewell	20-25000 rupees
distribution works	17-20000 rupees
mechanical and electrical works	20-23000 rupees
general investigation, transport and other charges	15000 rupees
working estimate for total	75-80000 rupees

Borewells were not without problems for farmers. Faulty installation of the pumps at inaccurate depths could mean that wells yielded less water than envisaged, and problems of pump maintenance were greater. Thus maintenance could also be a factor in technology choice (Interview, Executive Engineer, APSIDC Kurnool District, July 1983). However, to farmers, the attractions of borewells over dug wells greatly outweighed the disadvantages, except where dug wells experienced virtually a total subsidy. They were faster to develop, without the need to organise labour. However, it was the payment system which proved a major key. Finance on group wells assisted through the State Irrigation Development Corporation (APSIDC) was repaid as a water rate: while high at

first, this was reduced to the standard for other minor irrigation systems⁴. Also this cess was often not paid: during the 1980s APSIDC collected these charges, and arrears were extensive. This eventually brought financial problems into APSIDC, who in the early 1990's tried but failed to transfer the rate collection to the Revenue department (Interviews with: Chef Engineer APSIDC, 2000; NABARD officers at the NABARD workshop, Hyderabad, September 1995 and Hyderabad offices, November 2002).

4.2.4 Pumps and Power

At this time, the 5 hp motor was sanctioned for assistance under in development programmes, being one of the artefacts also manufactured by the state company Agro Pumps and Instruments Ltd (APIL). (From 1978, subsidy was also allowed on 7.5 hp engines⁵). Given the slow spread of electricity, diesel pumps still formed some 40% of the pumpsets in Rayakseema districts in 1983. However, the advantages of electricity as a source of power greatly outweighed those of diesel, which was subject to unreliable supply and was more expensive – to the extent of jeopardising returns on all but lucrative crops. The cheap tariff for electricity – then 50 rupees per hp per year – did not deter rapid expansion of illegal connections.

These, then, were the costs and issues confronting the development programmes for wells, to be compared with returns from irrigation, and bank loans and programme subsidies available. Costs seemed about the same order of magnitude for dugwells and borewells – but there were different dynamics in accessing and repaying credit and

⁴ Previously, this water rate was calculated on the basis of capital, interest, maintenance and depreciation charges up to a maximum limit of 400 Rs. per acre per crop for a site of ten acres or less, or 250 Rs. per acre per crop on a site of more than this. After an outcry over the differences between this rate and those levied on surface tanks, it was fixed as 50 Rs. per acre per crop, with an addition of an electricity charge of 50 Rs. per hp per year. The difference was subsidised by the Government, with the subsidy supposed to taper off after 6 or 7 years. The comparative advantage over repayment terms for a loan for a dug well are obvious.

⁵ The number allowed was supposed not to exceed 25% of all pumps up to 10 hp financed. See circular 9647/IDA-37-78-9, September 1978. in See Ministry of Agriculture, 1979, Government of India.

subsidies. However, well behaviour and reliability in supplying water, across the year, was also of major concern. Table 4.3 shows how these played into different technology choices across Kurnool district 1975-1983, based on loans released through ARDC/NABARD.

Table 4.3. Refinance through ARDC/NABARD, 1975-1983, Kurnool district

Taluk	NUMBERS			EXPENDITURE Lakhs Rs
	Dug wells	Well Deepening	Pumpsets	
Banaganapalli	161	171	94	15.52
Kurnool	306	46	136	17.42
Nandyal	465	211	425	53.55
Allagadda	92	71	84	10.33
Dhone	774	140	279	45.82
Pattikonda	49	50	37	4.63
Nandikothur	886	407	948	104.02
Adoni	806	259	566	60.91
Alur	352	113	178	20.47
Koilkuntla	390	181	224	31.76
Total	4281	1649	2971	364.43

Source: NABARD records, Kurnool District

Differences correlated partly with groundwater availability (poor for shallow groundwater in Alur, Koilkuntla, Banaganapalli and Nandyal taluks although borewells would later give better yields in the last two); relative interest in dug wells or in-well bores given older traditions of using wells (like Nandikothur and Adoni); and the interest of new special assistance programmes to move into blocks with a low level of canal irrigation which were also underdeveloped in their infrastructure and marketing (Dhone, Pattikonda, Alur, Koilkuntla). Blocks like Allagadda had low loans due to bank overdues and restrictions on credit. Thus dug wells, including with in-well bores, were being heavily promoted in certain blocks, just as borewell technology was coming into the region. In fact dug wells continued to be developed through the 1980's under certain programmes despite the growing interests and new agency development for

borewells. How this happened, and the problems resulting, is a critical theme in the rest of this chapter and the next.

4.3 AGENCIES FOR DEVELOPMENT IN THE DROUGHTPRONE AREAS

By the mid-1980s, the promotion of groundwater use through IRDP and DPAP brought a raft of new organisations into existence and interaction with each other, including for

- 1) data collection on water resources - the state groundwater department;
- 2) technology dissemination and technical intervention - the new state corporations;
- 3) disbursing credit and subsidies; the banks, the DRDA and the SCSTC;
- 4) regulating agencies at central level - ARDC/NABARD and the CGWB.

This section reviews the struggle of each agency to survive and develop particular operating norms, and shows how they linked together as a technoeconomic network

4.3.1 Data collection on water resources – the Groundwater Department

A regional office of the State Groundwater Department (SGWD) was set up for the Rayalaseema region in 1972 (located in Cuddapah) and branch offices were designated in 1975. In fact the office for Kurnool only began in 1983: it was awarded a cohort of seven geologists (but two were seconded to Anantapur) and two geophysicists. Central to the slow emergence of local offices was funding. In 1983 the state government awarded its GWD only 35 lakh rupees (about 195000 pounds) to be spent on exploration in their DPA. Thus the Kurnool office opened partly as a result of this special state allocation to the DPA, but also funding from the Central DPAP (5 lakh rupees or 25000 pounds) which allowed it to buy its one rig and jeep. (Interviews with Branch Officers of Groundwater Department in Kurnool and Anantapur districts, July 1983). This manpower and

equipment level was simply not enough to keep pace with the groundwater development scheduled within the DPAP and IRDP programmes as well as its general duties⁶, and no specific attention was made to any dimension of drought.

While considerable progress emerged with the mapping of groundwater levels and general geology, much of the drilling information to help estimate groundwater flow and recharge came from APSIDC. The SGWD at first was more like a data collection wing for the corporations (and the banks), serving their loan screening needs.

4.3.2 Technology dissemination - the new state corporations

The Kurnool office of the Andhra Pradesh State Irrigation Development Corporation (APSIDC) opened in 1978 and the Anantapur branch in 1981: by 1983 its engineers estimated they did about half the surveys for their own borewells (Interviews with District-level Executive Engineer, Kurnool District, July 1983). The Andhra Pradesh Corporation State Cooperative Rural Irrigation Corporation (APSCRIC) was also set up in 1981 to drill dug-cum-borewells (APSCRIC, 1981; interview with Chief Engineer, APSRIC, July 1983). The state corporations were an amalgam of state, central and private funds, organised into operating budgets and reserves which could continue to generate interest: they were also supposed to gain income from water rates charged on borewells installed. Central funds came in through special assistance programmes, and it was this funding that brought them under the scrutiny of ARDC/NABARD (which together with state funding sources were their real regulators). APSIDC ran a 'normal' scheme for all farmers, as well as supporting special assistance programmes with the DRDA office.

⁶These were (i) to make survey investigations and drawing up hydrogeological maps; (ii) to give groundwater clearance for schemes given credit by banks (iii) to make investigations for percolation tanks (iv) to make investigations for the corporations drilling borewells and dug-cum-borewells.

Their operating position was thus very different to a state department dependent on an annual budget.

There was no specific agency to manage dug wells. Funding programmes were handled by the DRDA and the SCSTC through their local officers. The pressures on these officers to disperse funds over large – and relatively distant – areas were massive, leaving opportunities for financial mismanagement and corruption. In 1983 the Anantapur DRDA proposed a Central Authority to coordinate well development⁷. The request was turned down, not because of opposition from other agencies, even though such an agency might be in competition with APSIDC. It was turned down because it involved a grant of money, without any loan component that would be paid (interviews, SCSTC and DRDA staff, Kurnool and Anantapur districts, September 1983).

4.3.3. Disbursing credit and subsidies; the banks, the DRDA and the SCSTC

The DRDA, responsible for coordinating programme funds such as the IRDP and DPAP also had serious manpower shortages: the DRDA staff in Kurnool consisted of a Project Director with just three technical assistants (typically animal husbandry, agriculture and sericulture), a credit officer and an accounts officer. The DRDA had no research funds, and was dependent on the knowledge of science and technology within the state agencies it worked with, or who seconded staff to the office. No-one could be seconded for groundwater, as there was no Ministry to provide this. The pressure to disburse funds pushed project development ahead of real knowledge about the resource base and farming systems of the locality concerned. The special corporations for scheduled castes,

⁷ It was argued that such an entity would greatly simplify procedures and cut costs for farmers by coordinating all involved activities, and estimated to cost only 650 rupees per new well – easily comparable with the costs from hiring in of contractors and equipment, and related delays (field interviews with SCST district staff, Kurnool and Anantapur, September, 1983)

scheduled tribes and backward classes also faced even worse manpower pressures and lack of resources for evaluation or research.

The IRDP, with its aim to generate additional employment and raise incomes for poor families, set the poverty line at an annual net income of 700 rupees or less. This was different from the conventional landholding criteria for categories for small and marginal farmers based on land ownership⁸ used by the DRDA, which also shaped bank lending policies. There were insufficient staff to collect or check this diverse information (even if it was collectable).

IRDP focused on weaker sections of the community – not only small and marginal farmers, but 50% of 'beneficiaries' were to be from scheduled castes and tribes. The programme included a range of activities of which irrigation was a supporting part for secure water supply – including sericulture, animal husbandry, horticulture, social forestry and fisheries. (APCCADB, 1983, 1980; DRDA office files, Kurnool district). The packages involved a loan repayable by the 'beneficiary', but also gave subsidies if actual development was very expensive or loans proved difficult to organise – as was typical for high cost wells, or loans to very poor farmers or special caste groups.

Successful expansion of wells under IRDP involved the cooperation of the banks in lending to small farmers, which was not very forthcoming at this time. (Khan, 1980; APCCADB, 1980). Most banks would only loan for minor irrigation if a farmer had four acres or more, and many banks used a criteria of 10 acres. Apart from insisting on land as collateral, for irrigation assistance, they used the value of land under dryland cultivation in loan assessment, which was typically only 1,000-3,000 rupees per acre value. All the banks assisting in the IRDP programme had a minimum landholding requirement to assist individual wells - usually 2½-3 acres for a well only, and 5-6 acres for a dug well and

⁸ An agricultural labourer/ marginal farmer was defined to have 1 acre or less, a small farmer 4 acres or less.

pumpset. (Agricultural labourers were only eligible for loans to a maximum of 3,100 rupees.) (sources: APCCADB, 1980; DRDA records, Kurnool district, and government circulars on financial assistance⁹) Thus reaching small farmers involved increasing amounts of subsidy alongside the loan component a bank would extend. However, despite huge subsidies that made loans very small in practice, there was still limited help. Certain banks (e.g. the Syndicate Bank) assisted community irrigation wells if they covered at least 1.5 acres and had at least three beneficiaries. It is hard to know whether 'community irrigation schemes' came about because they were genuinely wanted collective developments, or were simply designs that gave access to central funds and bank loans.

Another problem was the repayment terms relative to likely income from wells. In 1983, general rates of interest were 10%, with repayment terms of 9 years for large farmers and 12 years for small farmers. However, the repayment term for farmers receiving subsidies was reduced (because of a smaller loan): to only 5 years, and I saw one repayment schedule agreed of three years. Typically one could see a loan, after subsidy, of around 8,000 rupees for a well and pumpset, to be paid back at 10% interest over 5 years.

DPAP funds bought in twice the level of subsidies to a block as IRDP. Subsidies under the DPAP programme were first disbursed to a district per area of the programme: after 1979 they were issued in relation to blocks. DPAP funds were for 'droughtproofing' and restoration of ecological balance, and focused primarily on provision of communal resources, for which community dug wells and borewells were eligible. The DPAP could also give funding to the GWD for data collection.

⁹ Many of these are collected in Ministry of Agriculture (1979).

Thus the different technologies assisted under the different programmes were as follows:

Groundwater development under IRDP	Groundwater development under DPAP
Individual and communal hand-dug wells	Community borewell
Pumpsets	Community dugwells and in-well bores
Individual in-well bores	

The limited numbers of banks, their overdue levels, and unwillingness to assist small farmers visibly hampered programme work. This in turn put pressure on the DRDA to coordinate its work as much as possible with other programmes and agencies providing subsidies – margin money from the caste corporations, and also the irrigation corporations refinanced through ARDC. As will be shown, this often drove well development programmes into some of the weakest communities on the poorest land, sometimes bringing further risks into production in these area and communities if wells failed. Even by 1982, the Central DPAP taskforce lamented that the DRDA was coming to see its programmes just as ‘budgetary custom’, such that there was no real design of any programme (Government of India, 1982, p. iv). Thus they drew up a new 21 point plan that put strong emphasis into irrigation potential and watershed harvesting, as well as spatial data synthesis for local planning: whether this worked is a subject for later sections.

4.3.4 Regulatory agencies

All emerging processes left considerable power with the banks, yet they also had very poor levels of control, as they had no technical staff of their own. In fact it was hydrologists with ARDC who ended up drafting simple procedures for banks to follow - to estimate yields, irrigable areas and possible incomes, and appropriate pump sizes, as a

means to stop local banks from over-extending loans to against inappropriately sized well commands, or wrongly sized pumps¹⁰. They also took a firmer control over bank overdues, restricting flows of funds to banks with high outstanding repayment levels¹¹. ARDC/NABARD also oversaw the financial probity of the Irrigation Corporations, to audit expenditure of central funds and repayments of water charges that were supposed to replace capital expenditure.

4.4 THE 'NON-SCIENCE' OF GROUNDWATER PLANNING FOR SMALL FARMERS

As the previous section has shown, the pressure to develop groundwater led to creation of multiple agencies for resource assessment, technology dissemination and planning. However, these new state agencies had neither a historic sense of identity nor scientific credentials as seen in the agencies described in Chapter 3. While the Central Groundwater Board certainly did have a sense of scientific mission and purpose, this was hard to replicate meaningfully at first in the state groundwater agencies created, who inevitably just followed the models created by the central agency. What was emerging in the 1980's was a loose and uneasy coalition of agencies bound together by the funding patterns and programme directives emerging via state and central development policies. While all developed operational norms to help technology dissemination, none of these took any real cognisance of any dimension of drought – neither to limit development to lower recharge levels nor reflect of problems of low profitability if production options declined in a year when water levels fell early.

¹⁰ Guidelines for scrutiny of groundwater utilisation schemes projected under the normal lending programmes of the land development banks. These were seen as temporary until Groundwater Departments were better established and could develop improved norms. (Circulated with letter 10-571 Agri-Credit Board, 29.6.1972. See also Ministry of Agriculture, 1979)

¹¹ See Circulars on the Issue of loans by State Land Development Banks – Regulation of Advance (NoLDB, 1036/11 and 46-78/9 (January 1979) and Revised Norms (No ACD.DB. 11994/11, 46-78/9, January 1979), See Ministry of Agriculture, Government of India, (1979)

The 'science' for development had to be created from existing data sets, which became linked together as best as possible between basic scientific principles, empirical norms and pragmatic associations. This section summarises findings related to two critical quasi-scientific models used in the implementation of well development targets:

- technical appraisal routines to select and approve well dimensions and pump selection;
- estimation of groundwater yield, potential well numbers and well development options.

These explain also some of the problems in subsequent well development, the corruption related with this, and the negative impacts on some farmers outlined later in chapter 5. Critical evaluation of these models could have stopped some of these excesses, but did not.

In 1983, both these sets of estimation procedures in use had been created by ARDC/NABARD, rather than the technical or central scientific agencies just discussed. ARDC set up these simple models, in the hope that 'more scientific procedures' would follow later. There was a third area of science that later became important in dissemination of well technology. This was geophysical monitoring for presence of groundwater at a site, undertaken through resistivity measurements. This technology was only coming generally into use at this time. In my study area, the critical first stage in any site survey was still the digging of a trial pit to test drilling to see if water was present – both were also within the control of implementing agencies. Resistivity techniques are therefore not reviewed in this study.

4.4.1 Appraisal routines to select and approve well dimensions and pump selection

These technical appraisal procedures evolved in stages. First, calculation procedures were standardised, to assist in selection of appropriate pumps and groundwater works consistent with aquifer parameters and designed pump discharge. They were developed in principle to ensure costs were payable by small farmers, and to avoid problems of over capitalisation (pump size too large) and over- or under-financing. Second, standardised procedures were set up to equate estimated yields with irrigable area of borewells, and the profitability of irrigated production supported by the well (from which loans could be repaid (ARDC, 1980 (i) and (ii), NABARD, 1992).

Groundwater development in Rayachoti meant development in hardrock area where aquifers were known to have low and unpredictable yields and problematic fluctuations in water levels across seasons. Pressures to assist small farmers meant that agencies went ahead with well development with low yields, despite their high costs. For credit and special assistance much discussion centred on what yield should be available before a borewell was 'allowed' to be fully developed and declared successful. The limit used for a 'failed well' was only 2500 gallons per hour (gph) (3.2 l/s) for individual wells and 1200 gph (1.6 l/s) where a cluster of borewells has been developed. In fact the government agreed to the use of 1000 gph or less where scheduled castes or tribes benefited. (Interviews, APSIDC staff, August 1983) For in-well bores, the criterion for a failed well was 500 gph (0.6 l/s; APSCRIC, 1981). The 'rule of thumb' was that 1000 gph irrigated 3 acres of 'irrigated dry' crops in the kharif season and 2 acres of rabi¹².

At this time however, there was very little information on local aquifer characteristics. The CGWB continued some exploratory drilling: the SGWD only did

¹² the older levels of 4 acres and 3 acres respectively were considered too high by APSIDC field staff interviewed in July 1983.

exploratory drilling if it could fund this through special external assistance programmes. Thus the SGWD could do little more than extrapolate generalised estimates of yields in relation to geology and known performance under wells in other regions. Borewell drilling incorporated at best exploratory measurements done within them: geology was recorded, together with increases in flow recorded at different strata that were hit. However, no specific controlled pumping tests were done, from which storativity or transmissivity could be estimated. Bores were also typically left capped and undeveloped for 6-24 months between drilling and commissioning, given all the procedures needed to get funds and clearance for the screening and energising of the borewell. Kurien and Dholappa (1995) reviewed the gap between drilling yield and eventual operation yields across Rayalaseema. In wells left uncommissioned for up to 24 months, they found the reduction in yields to be 33-75% in the granitic gneisses, and 23-34% in the Deccan trap basalts.

Tables 4.2 and 4.4(a) show estimates calculated from data used by the SGWD and from APSIDC files in 1983, for likely irrigable areas under borewells in different formations. The crystalline hardrocks had low yields, typically irrigating less than a hectare, consequent to low sustainable pumping levels. Yields were only really adequate for wells irrigating larger areas under some cavernous limestone formations. Shales and quartzites also had low yields under dug wells¹³. To a large extent, low yields also characterised dug wells in the other main geological formation - the Cuddapah-Kurnool system, except where this contained limestone strata - specifically the Narji limestones¹⁴ - and some weathered quartzite zones in central and eastern zones of Kurnool. Alluvial

¹³ Subsequently borewell yields were improved for these formations consequent to both better exploratory methods and also drilling and development methods that opened up fractured/weathered areas in these rocks (interviews with APWELL project staff, Kurnool district, October 2002).

¹⁴ The Narji limestones had a well-developed cavern system for transmitting water. The Koilkuntla and Vampalle limestones had poorly developed solution and weathered zones and yield very little water, although the Koilkuntla limestones yield more in the most eastern parts of Kurnool district - either through the increased influence of faulting or recharge from the K.-C. canal irrigation scheme.

sands and gravels usually gave good yields of water but these were rare in Kurnool and Anantapur except in zones close to or within large-scale irrigated areas. Deep black soil areas also faced problems in well development - wells needed full lining to prevent the collapse of the well, making them very expensive to develop, and might also have water quality problems¹⁵.

Borewells or dugwells?

Tables 4.2 and 4.4(b) show that the low yields of some borewells in crystalline formations would barely irrigate 1 hectare - similar to that of a dug well (unless they were in a high recharge zone, say close to a tank). Thus borewells generally had little yield advantage over dug wells in the crystalline rocks, as both were simply tapping the water table of a weathered zone. The difference in advantage had to be weighed in relation to cost, employment generation, speed of results, management - and availability of subsidy. The prospects from borewell development were also not very encouraging. Where tubewells tapped across the various strata of the Kurnool system, they could be productive, and support irrigable areas of up to 15 hectares. However, there were also sites where an individual borewell might not support more than 2-3 hectares of 'irrigated dry' crops. The limitations of existing drilling technology (percussion drilling) meant borewells were then rarely drilled beyond 50 metres.

Table 4.4b shows that, in Kurnool district, over 40% of borewells drilled under special assistance programmes could irrigate less than 4 acres - a figure probably lower after borewells were finally commissioned. These low yields reflect the siting of wells for

¹⁵ Water quality problems in the black soils have different causes. In black soils developed over limestones and shales, salts present in water are a result of mineralisation and solution of the parent rocks. Reasonable sub-surface drainage means that salinity problems in black soils over limestone are rare. In the black soils developed over granites, the source of salts is the plant material from which soils developed, but poor sub-surface drainage and limited rainfall for flushing means high salinities and sodicity may be present. The blocks with the greatest problems are Alur, in eastern Kurnool district, and parts of northern Anantapur district. (SGWD, 1976: interviews with SGWD staff)

special target groups in more marginal lands with poorer aquifer potential. Yet often investments of up to 80000 rupees might have to be repaid from income from this area (unless costs could be reduced by shortcuts in construction or massive subsidies). However, the programmes never stopped – their mandate was to develop wells. In Kurnool, only 28 % of 'normal' borewells irrigated less than 4 acres in rabi, but 42 % of borewells developed under special assistance programmes fell in this range. Overall, 36 % of tubewells only supported 2-4 acres in the rabi season and overlap with the yield range of a dug well. These low yields came to haunt well programmes, especially ones promoting 'group wells' to serve such small areas. As water levels began to drop the risks of loss and bankruptcy occurred (see Chapter 5).

Summarising technology options across the geology - over the Narji limestone and quartzites, prospects for dug well development were good, but tubewells tapping additional strata at depth would give even better yields and assist more irrigators. On the shales, both dug wells and borewells had limited prospects, although borewells might strike water-bearing strata at depth with good exploratory techniques. In granite rocks, there was little yield difference between borewells and dug wells. In favourable fissured zones, borewells picked up higher yields as they tapped a greater depth but could face a collapse problem. Elsewhere there might be advantages to a dug well, with an in-well bore, as a farmer had a better reservoir of water to pump.

Thus for yield, the advantages of borewells was only clear for favourable sites in the Cuddapah-Kurnool system, or deep fissure zones in granites and schists without collapsing strata. However, funding programmes and politics helped drive actual technologies disseminated, and not always evaluation of best options.

Table 4.4a. Groundwater parameters influencing borewell and filter point development (source: Groundwater Department 1981,1976)

Rock type	Transmissivity m ³ /day/m	Depth to water bearing strata (m)	Sustainable pumping litres/hour (for 4 hours)	Irrigable area Wet crops (using discharge factor of 7 litres/sec)	(hectares) Irrigated dry crops (using discharge factor of 4.3 litres/sec)
Crystallines	10-100	10-20	<1000 -12000	0-0.5	0-0.75
Shales	1-130	20-75	4000-8000	0.1-0.3	0.2-0.5
Limestones					
• Narji	)	)	35000-200000	1.3-7.9	2.2-13
• Koilkuntla	)	30-60	3500-50000	0.1-2	0.22-3.3
• Vempalle	)	)	5500-11300	0.7-11	1.2-1.9
Quartzites	50-300	No data	20000-30000	0.7-1.1	1.2-1.9
Alluvial Infill	400-5000	4-29	30000-300000	1.1-11.9	1.9-19.3

Table 4.4b Range of borewell yields under various borewell programmes, Kurnool district Source: APSIDC records, 1983)

Range of yields Gph	Irrigable area (rabi) (acres)	'Normal's chemes %	DPAP %	Special drought Relief%	Scheduled caste	All special assistance schemes	Total
1001-20000	2-4	28.1	48.9	38.7	39.3	41.8	36.5
2001-5000	4-10	29.8	43.8	48.4	35.7	42.9	37
50001-10000	10-20	31.6	9.3	6.5	17.8	11.0	18.9
10001-25000	20-50	10.5	-	6.5	7.1	4.5	6.7

Drawdown, specific capacity and irrigable area under dug wells

The models first developed usually took a model farm of 3 acres, which had emerged as the minimum holding banks would loan against. In fact, this was probably the minimum area against which unsubsidised development would make any profit. In the models, these farmers also produced in three cropping seasons throughout the year – even into summer – which rarely occurred in practice after the 1980s as water levels fell. The unit costs given for wells even in 1988 were only 16000 rupees, or 24000 rupees with a pumpset. Even then the repayment norms were 40% of the net income from crops identified as feasible to be grown. (ARDC, 1980 (i) and (ii); Kurnool District DRDA records, August 1983).

The model then estimated what diameter of dug well would provide the required water, for a given drawdown of water-levels. The norm set up was for operating 4 hours a day, with a maximal drawdown of 2-3 metres, with water levels ideally recovering overnight. Calculations with the lower yields from wells in hardrock areas indicated that pumps of only 2 or 3 hp were necessary for lifts which were then shallower. However, the influence of APIL meant that 5hp pumps were most common in energised wells. If operated for four hours a day this pump would lift between 250-400m³ of water, about the same as a 2-4 metre drop in wells of the 10 metre diameter discussed (such a drop is considered maximal in good design practice). Thus the control on the area irrigable was the rate of replenishment of the well.

Thus a criterion very important in Indian well design – specific capacity (or litre per minute released per metre drawdown in water level) became embedded in equations of the model. If the aquifer did not recharge within 24 hours, then the well needed to act as a reservoir to provide the volume for pumping within the given drawdown range. In such cases, the well diameter was accordingly increased, based on simplified and standardised calculation procedures derived from scientific formulae for estimating these dimensions (modified Thiem and Sligter's formulae). These were used to estimate well dimensions

and recharge time, sufficient to fill the well to support periods of pumping: results from use of these equations for dug wells are also shown in Table 4.4a. Clearly many crystalline rock formations had a specific capacity where wells did not recharge within 24 hour to sustain a reasonable period of pumping, and needed large diameters. These principles were already known locally, as large diameter wells were a known feature of parts of Rayalaseema. However, these larger well sizes affected cost estimates for new excavation, and could not support intensive production.

Table 4.5 shows my calculations of the typical area under different crops irrigable with a 2-3 metre drawdown of water every day (a four hour pumping period would lift enough water to irrigate one third-one half hectare every day, with blocks of land being irrigated in rotation).

Typically, wells of the diameter mentioned would support an area of around four hectares of 'irrigated dry' crops, if some water was available for irrigation every day. However, wells with sites of slower recharge, for example those recharging every five days, would only irrigate 0.5-1 hectare. These were hardly an economic proposition, given their costs, unless there was extensive subsidy. Such wells were implemented, however.

Profit margins in production

Given the scale of loans in well assistance programmes, the economic returns on crops produced were obviously of central importance. In Kurnool at this time, rice was found on 25% wells, groundnut on 22%, chilies on 11% and onions and vegetables on 14%, with some 16% having 'other crops' (Seasonal and Crop Report, 1980-1981). This greater proportion under groundnuts, chilies and vegetables probably reflected availability of interstate road and rail infrastructure, or relative proximity to Hyderabad offering reasonable prospects for vegetable production. Rice remained the main wet crop, with little expansion into sugarcane at this time.

Table 4.5. Areas irrigable from a dug well pumping at 20 litres per second¹ for four hours

Crop	Discharge factor ² Litres per second per hectare	Areas irrigable (hectares) Recharge within:		
		24hrs ³	5days ⁴	12days ⁵
<u>'Wet' crops</u>				
sugar cane	5.25	3.8	0.7	0.3
paddy	7.5	2.6	0.5	0.2
<u>'Irrigated dry' crops</u>				
wheat	2.91	6.8	1.3	0.5
cotton	3.35	5.9	1.1	0.4
maize	2.91	6.8	1.3	0.5
tobacco	3.4	5.8	1.1	0.4
chilies	4.37	4.6	0.9	0.3
jowar	4.37	4.6	0.9	0.3
onions	3.88	5.1	1.0	0.4
bananas	4.37	4.6	0.9	0.3
vegetables	2.33	8.5	1.7	0.7
fodder	4.2	4.7	0.9	0.3

(compiled from own calculations)

1. A 5 hp pump operating at 50 per cent efficiency lifting water through a head of 10 metres would pump 19 l/s: at a head of 8 metres the rate would be 24 l/s. In the field, few dugwells had pumps actually delivering this amount.
2. Information for Andhra Pradesh, linking depth of irrigation water required with the rotation interval (see ARDC, unpublished data 1).
3. The rate of 20 l/s divided by the discharge factor.
4. The area irrigable at 24 hour recharge divided by 5.
5. The area irrigable at 24 hour recharge divided by 12.

Because of the low yields or low reliability of water supplies available, the emphasis under special programmes after the 1980's was on 'irrigated dry' crops, promoting:

- mulberry for sericulture in areas where infrastructure exists;
- citrus and mango production in areas with good transport infrastructure;
- more systematic production of fodder to support livestock and dairying;
- vegetables to improve nutrition;
- fuel and timber crops, especially in more remote areas.

Table 4.6 shows envisaged returns for these crops for this period. Clearly, the returns for certain irrigated crops were high, but these depended on fairly high input expenditure.

Thus, at their most favourable, the net returns on groundnut could be 3,900 rupees¹⁶ per acre, but only 500 rupees per acre if there was low use of inputs. Returns on grape, citrus and mulberry were very high, but only feasible with high levels of inputs, reliable water and a good extension service for cultivation advice. These crops also had long gestation periods. The banks made special loans available for citrus and grape development to allow for this longer period to full production. However, by the early 1980s few small farmers were involved in this production.

Table 4.6 Returns per acre of crops envisaged under minor irrigation (1982 costs)

<u>Crop</u>	Gross Returns Product Fodder Total			Cultivation Costs	Net Returns (Rs)
<u>Existing irrigated production</u>					
Groundnut	800	200	1000	500	500
Sorghum	240	200	440	200	240
Millet	240	60	300	150	150
Ragi	240	200	640	400	240
<u>Improved irrigated production</u>					
Groundnut					
Sorghum	4800	300	5100	1200	3000
(hybrid)	3000	500	3500	1000	2500
Ragi					
Vegetables	1800	300	2100	600	1500
Fodder	-	4500	4500	1500	3000
Grapes	5000	-	5000	1000	4000
Citrus	36000	-	36000	16000	20000
Mulberry	15000	-	15000	5000	10000
	10000	-	10000	2000	8000

Source: Kurnool District, DRDA office, 1983

4.4.2 The estimation of groundwater yield and well development options

Estimation of groundwater recharge and safe yield for development was undertaken primarily to estimate the development potential of a block, its state of development, and

¹⁶in 1983 £1 = 15 rupees

thus potential new numbers of wells. ARDC set up the first highly empirical guidelines for assessing potential groundwater.¹⁷ The model in use at the time of this study was initiated by a Groundwater Overexploitation Committee, also set up by ARDC, in 1977. The model began with compiling evidence of sources of recharge. In 1982 another committee was constituted with members drawn from the Central Groundwater Board, SGWD and other scientists to create the methodology known as the Groundwater Estimation Committee Method 1984 (GEC Method, see NABARD, 1986). However, this methodology did not get used in Andhra Pradesh until 1993 (and in fact did not make major changes from the original approach). The 1977 method involved mapping of changes in water level before, during and after the kharif monsoon period, at key observation wells. By interpolating flownets (from groundwater level contours), zones could be mapped of specific ranges of change in water level. By relating this with the specific yield (storativity) of the aquifer, seasonal fluctuations could be converted to volumes of water. Increased exploratory drilling did come to improve these estimates. The GEC method used a recharge criteria based on 10% of the average monsoon rainfall - 70% of this was regarded as usable annual recharge. Thus drought and abnormal rainfall hardly figured. In addition, recharge from post monsoon rainfall (P) was estimated by an empirical formula, and other general formulae were in use to estimate recharge from canal seepage (C) and irrigation (I).

Draft or actual use was estimated from either:

- generalised consumption requirements for irrigated crops and population estimates;
- numbers of wells, for which standard unit consumption norms were in place derived from pump discharges and estimated hours of operation, given below.

¹⁷ Guidelines for scrutiny of groundwater utilisation schemes projected under the normal lending programmes of the land development banks. Circulated with letter 10-571 Agri-Credit Board, 29.6.1972. See Ministry of Agriculture, 1979, Government of India: Credit for minor irrigation: A compendium of circulars (1979).

Working norms in use in 1980's

	Annual draft Ha.m		Unit	draft	Net
	Kharif(monsoon)	Post kharif (monsoon)			
Hard rocks:					
Dug well	0.15	0.35	0.5		0.35
Dugwell with Pumpset	0.4	0.84	1.2		0.84

Working norms later applied in APSGWB from 1993 (*relevant to this study)

Mhot well	0.35*
Dugwell with pumpset	0.65*
Borewell	1.30*
Shallow tubewell	2.05
Tubewell	4.1
Deep tubewell	5.25

The figure of 1.2 ha.m is equivalent to using a 5hp pump for four hours daily (the standard model) for 180 days.

Groundwater-based irrigation was allowed to use up to 85% of net utilisable recharge, with the balance allowed for domestic use. Initially, growth rates in borewell numbers were extrapolated at 1% a year. ARDC knew the approach was a simple one (see footnote 19), and looked for some rapid development of science by others – instead their norms became embedded.

Other criticisms of the time included that observation wells were sparse, and taken to represent wide areas. They were also often sited in towns: thus they also often did not reflect the real changes of water levels in agricultural areas where groundwater was being developed. Criticism also came on the infrequent measurements of water levels, at this time only once a year before the monsoon. However, the real concern was whether the increasing number of wells and borewells being drilled were actually recorded, and whether the estimated draft was correct or not. Where electricity and water was available, the use of 1.2 ha.m of water per year seemed a likely if not conservative level of use, but it remained a figure applied to borewells until 1993. After

1993 the working norm for draft under a dug well was actually decreased. By 1983 then, some cognitive problems were already clear. While the methods for groundwater estimation could count numbers of wells and types of wells, local agencies did not include detailed information on pumping regimes, nor on real groundwater conditions as they changed between seasons.

4.5 WHAT HAPPENED UNDER BOREWELL PROGRAMMES

As this discussion has highlighted, yields alone did not determine the development of well technology: finance was also critical, with cost advantages to farmers who could put pressure on authorities for a borewell. Borewells became a recognised element of funding in the DPAP, drought relief and special programmes for scheduled castes and tribes. Against a unit cost of 80,000 Rs, group borewells attracted a 50 per cent subsidy under the DPAP, with the remainder contributed by APSIDC (refinanced through NABARD), to be repaid as a water cess. As difficulties were faced in executing dug wells, especially with the unwilling involvement of banks, so the attractiveness of borewell programmes increased. During 1980-1983 a very high proportion of APSIDC work was with special programmes, while the backlog of applications for tubewells under normal schemes grew because of lack of staff. (Interviews with Executive Engineer Kurnool district, July and August, 1983). They made no real recognition of the risks of groundwater drought either from low rainfall affecting recharge, or any detailed local studies of water table decline across the years or between years.

4.5.1 Problems in borewell development

As already noted, borewell development by agencies was still in its early stages in Kurnool at the time of this study. APSIDC was under great pressure to expand its schemes, and in 1983 was permitted to subcontract work out to private contractors. In Kurnool district, the targets set in Autumn 1983 were 25 borewells a month - 10 drilled by APSIDC rigs and 15 by contractors. While initially three contractors were hired, this was reduced to only one, selected after tender by APSIDC, to ensure 'continuous work' for the contractor. These contractors had a three-year agreement with APSIDC.

Contractors were actually paid a lower rate per metre (220 Rs) than that allowed for the State rigs (285 Rs), on the basis that contractors carried no establishment charges. Contractors also had a freer choice of rig and spares, and newer equipment, than those in use by APSIDC. One private contractor in Kurnool (interviewed in the field in September 1983) reckoned that private rigs could drill up to five times as many bores as State rigs in a given period because of higher efficiencies. APSIDC provided costs for diesel for drilling and the casing for a standard depth of 6 metres, and paid a transport rate between drilling sites. Another contractor interviewed in the same period reckoned that he broke even on 15-20 bores a month, and that in every 100000 rupees worth of work (about 10 bores) he made around 25000 rupees of profit. A contractor was permitted to take on additional private work in an area if he had met the APSIDC target and APSIDC had no additional work in the area. While the potential profits for some contractors appeared considerable, many established contracting firms disliked working for the Government because of their slow payment. One contractor quoted money still pending for work undertaken 3 years ago.

APSIDC had an assistant present with the drill rig. Information and samples were recorded every 2 metres depth from where water was hit, with the drilling discharge

measured by a V-notch weir. However, this still left quite a few problems in drilling management. One contractor interviewed had no previous drilling experience, he was a relative of the Hyderabad company who had won the contract, and until two months previously had been running a hotel. He did, however, have a drill operator who did have 7 years experience in Hyderabad and Anantapur. Of the 7 wells this contractor had drilled so far, 2 had collapsed because the 6 metre casing did not extend deep enough to screen off weathered material. He admitted that he might not drill to the anticipated 50 metres if there was 'adequate water', though drilling to a shallow depth would reduce discharge. There were also problems in the way the discharge of the well was measured. Drilling discharge is not an adequate representation of potential discharge for regular pumping. This is one reason why group borewells frequently came to irrigate an area smaller than envisaged (the other reason was faulty pump installation).

Despite demand on APSIDC, its development work was slowed by several problems. The first was inadequacy of electricity supply: then typically schemes waited two years to be energised. Often programme demands required APSIDC to ground their schemes in areas without electricity - and then develop them in clusters in order to get the State Electricity Board (SEB) to extend lines to them. (Interviews with APSIDC Executive Engineer Kurnool district, July-August, 1983). The SEB would fund lines if costs worked out at less than 90 rupees per hp of the pump but otherwise APSIDC had to subsidise the work. In sites where a cluster of borewells was developed, a local supervisor was available, but elsewhere a maintenance supervisor was scheduled to visit every 15-30 days.

Table 4.7 Borewell development by APSIDC, Kurnool district 1984 (source APSIDC records provided 1983

	Total bores	Total Successful	NORMAL Total	NORMAL Successful	NORMAL STC	SPECIAL Total	ASSISTANCE Successful	SCHEMES STC
Atmakur	4	2	-	-	-	4	2	2
Nandyal	61	52	32	28	12	29	24	19
Allagadda	7	2	1	1	-	6	1	1
Nandikothur	6	1	-	-	-	6	1	1
Banaganapa	18	16	13	13	13	5	3	3
Koilkuntla	-	-	-	-	-	-	-	-
Kurnool	4	2	-	-	-	4	1	-
Dhone	19	17	3	3	3	16	13	13
Yemmegan	2	-	2	-	-	-	-	-
Adoni	7	3	-	-	-	7	3	3
Alur	18	14	1	-	-	17	14	14
Pattikonda	41	27	3	1	1	38	26	26
TOTAL	187	136	55	55 (83%)	46	132	88 (66%)	82

STC Still to be commissioned

Some of the greatest maintenance and breakdown problems stemmed from fluctuations in voltage in electricity. The total pump life was envisaged as around 9 years, with 2-3 years maintenance free (without voltage fluctuations). However, such fluctuations could ruin a pump within six months, with a 3-4000 rupee replacement cost. Damaged pumps were sometimes replaced with a pump of lower capacity. (Interviews with local APSIDC assistant engineers and operators, September-November, 1983). At one borewell site visited in Anantapur (1983), a supervisor claimed that over 10 per cent of pumps installed in the last 3 months had been lost because of voltage fluctuations. There were also problems of failed wells as well as low yields. Table 4.7 shows the pattern of borewell development under the different programmes, with borewell numbers, spread differentially across the taluks with better groundwater resources. However, it also shows a 28% failure overall: 17% in the 'normal programme' but 34% of borewells drilled under special assistance programmes.

4.5.2 Who got the borewells

Table 4.8 shows the number of beneficiaries and average area per APSIDC borewell in Kurnool district: this gives some indication of the types of beneficiary in the command area of the tubewell, as well as the number amongst whom management of water had to be organised.

If the average plot size under by the borewell was more than 2 hectares, then larger farmers were certainly present, possibly indicating infringement of land ceiling legislation (the limit on land holdings under tubewell irrigation was between 7 and 10 hectares depending on crops grown).

Table 4.8.¹⁸ Average size of holding and number of beneficiaries per group borewell, Kurnool district (Figures show the number of wells)

Average per beneficiary (hectares)	Number of beneficiaries				
	1	2	3-10	11-20	Over 20
<u>Special assistance schemes</u>					
0-1					
1.1-2		3	35	6	1
2.1-5		6	27	1	
5.1-10		1	2	3	
10.1-25					
<u>Normal Schemes</u>					
0-1		3	8	5	2
1.1-2		1	15	2	1
2.1-5			2		
5.1-10		1	2		
10.1-25		1			
Over 25					

(source: APSIDC records, Kurnool district, provided July-September 1983)

Amongst special assistance schemes it seemed there were borewells serving a range of farmer classes, raising concern over the effect of the presence of one larger farmer amongst several smaller ones in terms of control. While 3-10 beneficiaries was the typical range of members per borewell, some special assistance borewells had only two beneficiaries. Conversely, however, there were borewells with very high numbers of potential beneficiaries within the potential ayacut area. I could only speculate in 1983 whether such high collective numbers on small areas really existed beyond paper registration.

The possibility that some schemes developed under the 'normal' programme were not reported (possibly due to infringing land ceiling legislation) was indicated by the low borewell numbers reported in the Agricultural Census. For the 1982/83 Census, only 7 tubewells were reported in Kurnool district, all in Nandyal block, but at least 16 wells had been commissioned by APSIDC by that date, apart from private

¹⁸ There are possible errors here, as often records showed only hypothetical areas irrigable from the drilling discharge of non-energised wells, and the number of beneficiaries in the vicinity. When a cluster of wells was developed, it was not clear if a beneficiary had land under more than one well.

developments. Thus even as early as 1983, there was real uncertainty about the real state of borewell development.

4.6 WHAT HAPPENED TO DUG WELLS: OVER-EXPANSION AND UNDER-REPORTING

Dug wells continued to be promoted well into the 1990s, even though they became vulnerable to drying up as borewell numbers expanded (see next chapter). Within Rayalaseema three types of schemes emerged to assist dug-well development:

- i) general bank loans to assist individual farmers without subsidies;
- ii) individual wells assisted partly by bank loans and partly by a subsidy under IRDP;
- iii) community irrigation (CI) wells. These had a chequered history in Rayalaseema: by 1982, they were only being actively developed in Kurnool district. These were funded by DPAP, drought relief and SCSTC funds.

Dug wells were uncertain in their development costs, depending on excavation and blasting needs. The main IRDP assistance to individual farmers was on the basis of unit cost of 10,000 rupees for a dug well and 5,000 rupees for a pump. However, at 1983/84 prices, 10,000 rupees barely covered the cost of excavating a well not requiring blasting¹⁹, and certainly did not cover the cost of lining. On the more marginal lands, more likely to be occupied by weaker sections, the problems of costs and low yields led to the idea of community wells, which might have to irrigate land of really very low quality. In this context, a programme emerged for 'social forestry' community wells, specifically designed to produce tree crops like *subabul* and eucalyptus. Community wells were given

¹⁹It was only half the cost of excavation alone for a well requiring blasting. It would just cover the cost of excavating 4 metres and inserting an in-well bore, (but in practice separate loan arrangements would have to be made for the two components!). The figure of 15,000 rupees for a community well would cover excavation costs of a deep hardrock well at 1980 prices, but was already inadequate for this by 1983/84.

a unit cost of 15,000 rupees, a higher cost that was a way to increase the actual subsidy to assist weaker sections. (Kurnool District, DRDA Office Records, August 1983). Appendix 5 gives details of three 'community wells', where lining, depth and baling²⁰ charges are all adjusted to keep to exactly this subsidy of 15000 rupees. Well lining was the main component dropped to reduce costs, although in theory banks would not release funds for a pump unless lining was completed. However, the biggest administrative headache was ensuring that claims matched the work done, both for material excavated and the rates of pay to labourers: this spawned the corruption documented later in this section.

4.6.1 Individual well development under normal loans and special schemes

A study of the Andhra Pradesh Cooperative Central Agricultural Development Bank (APCCADB) showed that between 1976-1982, (once the special assistance programmes were launched) most well developments were funded through special programmes targeted not just at small farmers but also excluded groups. In Kurnool district, the APCCADB recorded only 168 dug wells financed under normal loans, compared to 2754 wells under 'special programmes' (in Anantapur the ratio was 5:6601 showing even greater emphasis on small farmers). Larger farmers may have been already opting for borewells, or going to other funding sources. However, assistance to larger farmers was also hidden by the criteria used by the bank to classify a small farmer²¹. Thanks to this criterion, APCCADB did achieve its target at first to give more than 50% of well-related loans to small farmers in most blocks of Kurnool,

²⁰ Banks would not disburse funds for pumps before wells were completed, so pumps for baling were hired!

²¹ APCCADB used the criteria of a holding of ten acres as a definition for a small farmer, compared with four acres in use by the IRDP.

district except in Pattikonda, Koilkuntla and Allagadda where loans became restricted by bank overdues. Table 4.9 shows the relatively low numbers of wells funded under IRDP by 1983, most occurring in areas with a tradition of dug well use.

Table 4.9 Cases of assistance under IRDP up to December 1983, Kurnool district.

Taluk	Wells	Deepening of wells	Pumpsets
Kurnool	13	62	33
Dhone	4	1	1
Nandikothur	111	25	25
Atmakur	79	7	7
Nandyal	no data	no data	nd
Banaganapalli	6	-	-
Koilkuntla	-	1	1
Alur	13	-	-
Pattikonda	6	-	-
Adoni	49	-	-
Allagadda	26	-	-

Source: Kurnool District DRDA records, 1983.

Given these problems, to extend its minor irrigation programme in Kurnool district, the DRDA had to turn to other irrigation developments - community irrigation wells.

4.6.2 Community irrigation wells in Kurnool district

Community irrigation (CI) wells have represented one of the more problematic components in minor irrigation developments under groundwater, in their implementation, management and maintenance. They persisted in Kurnool partly because the slow progress of well development left them an ongoing part of the development programme. They also persisted because they remained the only developments possible for subsidies allocated for communal programmes, given the combination of high costs and unwilling bank participation. CI well development could utilise several sets of funds:

- special assistance funds for scheduled castes and tribes, often spent in conjunction with DRDA funds because of limited manpower in the administration of these groups;
- drought relief funds;

- funds from the DPAP;
- funds from IRDP.

Another reason why CI wells were such a strong component of the minor irrigation programme in Kurnool was the difficulties the DRDA office had in allocating funds for minor irrigation. Drought relief funds had to be spent in the drought-stricken block, and DPAP funds did need to be spent across the region they are allocated for. Unlike Anantapur, Kurnool did not have extensive terrain suited to tanks, nor a large number of abandoned tanks for conversion to percolation tanks, on which money could otherwise be spent. Also, the recent arrival of APSIDC activity in Kurnool district meant that funds could not yet be massively allocated for tubewell development. CI wells proved an expensive component of drought relief. However, the combination of above funds meant that the full expense of community wells could be met, and that available funds were actually utilised. Community irrigation wells were possibly also the only developments the Kurnool administration could mobilise immediately to benefit some weaker sections during a drought event.

In 1982, Kurnool had three main programmes of CI wells operating:-

- (i) wells commenced under the 'Food for Work Programme' (FFWP) launched in 1979;
- (ii) wells commenced under the 'Scheduled Caste Action Plan and Drought Relief' launched in assigned and surplus land²² begun in 1982. This programme included the 'Social Forestry wells' operating in land of marginal quality;
- (iii) a new plan for CI wells was being organised to utilise a special 3.5 lakh Central Assistance Fund awarded in 1983.

(sources: Kurnool Office DRDA records: interview with District Officer for Kurnool District, November, 1983)

²² assigned land is land not registered as private holdings and is typically marginal hill land or tank bed land. Surplus lands are those reallocated after land ceiling enforcement.

The combination of subsidy and loans for (ii) and (iii) developed out of some difficult experiences under the earlier 'Food For Work' Programme (FFWP) from 1977, which aimed to utilise available food grains for generating employment and creating durable community assets to strengthen rural infrastructure. Problems included the actual availability of foodgrains (acquisition and delivery), poor control over development costs of wells within the programme, malpractice between contractors and local representatives, and that wells benefited only 1-2 farmers²³ and thus were not true community assets. Later programmes reduced the food supply element in favour of grant or subsidy. My 1983 study traced some of these problems, to try and disentangle the problems of good technical assessment from the pressures of financial disbursement and corrupt practice.

CI wells were supposed to serve at least three acres and be communal assets: they were also supposed to be launched in 'assigned' or 'surplus land' – land not registered as private land (e.g. land assigned for scheduled castes and tribes, or surplus land taken up from land ceiling legislation). The former was often marginal quality land – often in hilly areas - with poor water potential, where water was unlikely to remain sufficient to irrigated 3 acres across a year. Table 4.10 shows the numbers of beneficiaries per FFWP CI well. Over two-thirds of the wells developed for Scheduled Castes had only 2 users.

While special programmes could subsidise virtually all components of well development, often loans were still needed to acquire a pump. Yet most banks would only consider loans to individuals or groups holding land in their own name – which also pushed the programme towards groups on 'private' land. Looking at the FFWP,

²³ Only small and marginal farmers, or farmers below the poverty line were supposed to benefit from CI wells. The programme allowed for 'local technical institutions' to assist in planning projects, but was specific that contractors should not be used in work or food distribution. The food component was

Table 4.11 shows that most development was on private holdings – and also that the numbers of CI wells developed was substantial. The assistance for the FFWP wells was based on a unit cost of only 16,000 rupees; 10,000 rupees for excavation and 6,000 rupees

Table 4.10. Beneficiaries per CI well under the FFWP sanctioned for Scheduled Castes

Block	Number of wells with Number of beneficiaries			
	1	2	3-6	7 or more
Kurnool	2	25		
Kodumur		24		
Dhone	16	25	13	7
Nandikothur		39	8	2
Atmakur		33	19	
Nandyal		18	23	
Allagadda		23	13	
Koilkuntla		1	1	
Banaganapalli		6	2	
Adoni	2	16	6	
Alur	5	4	1	
Pattikonda		26	7	1
Yemmiganur		22	15	
Total	25	262	109	10

Source: Kurnool Office, DRDA records. 1983).

for lining and pumpsets. This was quite adequate in the early stages of the project, when the excavation cost was to be covered through food grain allocation, and the lining costs through DPAP funds (at this time IRDP was not in existence). With the subsequent lack of foodgrains, 'margin money' of 2,000 R was brought in from SCSTC assistance against part of the excavation cost, leaving an oil engine costed for a loan of 4,000 R to be sought after the well was completed.

allocated through Panchayat organisations, the wells developed were to be maintained by the Panchayat and water rates to be paid by beneficiaries were fixed by the Revenue authorities.

Table 4.11. % wells taken up in various types of landholding under the FFWP

Block	Total number of Wells scheduled	% developed in		
		assigned	surplus land	patta
Atmakur	228	3.1	1.7	95.2
Dhone	158	19.0	-	81.0
Kodumur	91	-	3.2	96.7
Kurnool	91	12.0	3.2	84.6
Nandikothur	146	30.1	1.4	68.5
Allagadda	242	9.9	-	94.2
Banaganapalli	18	-	-	100.0
Koilkuntla	3	-	-	100.0
Dyal	134	12.7	13.4	73.9
Adoni	42	16.6	14.2	69.0
Alur	33	6.0	9.0	84.8
Pattikonda	104	13.5	-	86.5
Yemmiganur	148	10.1	4.0	85.8
Total	1438	11.2	3.1	85.7

Source: Kurnool District DRDA records, 1983.

4.6.3 Technical clearance, disbursement pressure and scope for corruption

In late 1978/early 1979 the Collector instructed Block Development Officers (BDO's) to investigate trial pits for possible CI wells to be executed under FFWP. In fact there was no systematic groundwater survey by any qualified agencies for these programmes, but BDO's were supposed to ensure the presence of water before well excavation commenced. Disbursement records were kept at village level, but without detailed map references. I had insufficient time to really map any of these wells before the corruption started to become clear from the files and preliminary field visits.

The first round of requests from BDO's for wells under FFWP in 1979 is indicated in Table 4.12, which shows the scale of work first claimed against work actually confirmed on the ground in 1983. Most BDO's claimed that work had commenced immediately, and by March 1979 had sent in claims for subsidies for ongoing wells, especially for those nearing completion. In March subsidies of around 3,000 rupees per

well were released as a first instalment for all wells listed as 'near completion'. Concern at the advance demand of funds led to a subsequent survey of the actual number of wells grounded in August 1979, shown in Table 4.13. Discrepancies between initial well numbers claimed and those confirmed in the survey were very serious in Dhone, Alur, Nandikothur and Pattikonda. However, since subsidies had been released only in relation to wells claimed as nearing completion, the blocks with remaining substantial discrepancies were Dhone, Alur and Nandyal. This confirmed list was the basis of a revised programme of 1,200 community wells in 1981.

Given the time needed to develop a dug well, it was not surprising that only a proportion of the agreed wells were completed by the cessation of the FFWP programme in 1980. The progress of the wells was worsened by the slow and intermittent flow of foodgrains. But this was not the real problem. It was hard not to see advances still outstanding by 1982 as an indicator of financial mismanagement by BDO's.

I took up study of these events in Dhone block, as a block with a large number of wells registered that could be studied, that was also easier to visit than the other more distant blocks. I used DRDA and Panchayat Samiti files (and lists of beneficiaries given for 1978/79) to see what programmes had assisted which well development component, then tried to visit these wells in the field to learn more about their development and performance. In fact the extent of malpractice present made this work almost impossible. I was able to visit some wells: however, in some villages where headmen had been coordinators of work, I was not even sure I was taken to the correct well. In another incident, my camera was stolen and the office officials 'casually' started naming the son of my key informant as the possible thief. Quite quickly, my work, and the support of those trying to help me, became untenable. I soon ceased further study on these wells (November, 1983).

Table 4.12. Progress of wells under the 'Food for Work' Programme in Kurnool District (Source: Kurnool District DRDA records, 1983)

Blocks	Initial numbers of wells claimed by BDO's as in progress March 1979	Numbers for which subsidies were released 1979	Final numbers of wells confirmed in the survey	Submission by BDO as 'Completed in all respects' May 1980	Confirmed completed September 1983	
hone	250	208	158	201	107	57
Nandyal	195	195	134	141	31	58
Allagadda	256	217	242	242	120	150
Pattikonda	178	105	104	104	-	14
Alur	213	64	34	34	1	4
Adoni	50	40	42	42	17	25
Yemmiganur	150	150	148	148	86	118
Nandikothur	216	120	146	146	n.d.	123
Kurnool	218	100	91	91	12	45
Kodumur	n.d.	101	91	91	91	45
Atmakur	n.d.	200	229	229	96	189
Koilkuntla	n.d.	5	3	3	5	3
Banaganapalli	25	18	18	18	5	18

Nevertheless, correspondence in the files enabled the following picture to be built up. The following paragraphs draw on correspondence 1979-83 between;

- the State Government, Panchayat Raj department on what could be on CI programmes and what could constitute a CI well and issues of food for work (letters 29843/DPAPII/17; 497/FFWP/79.1; 4/FFWP/78-34;
- between the DRDA Kurnool office and BDOs in 1982 and 1983;
- Office notes on problems and cost estimates (619/79);
- Kurnool District DPAP Master Plan, 1978-83;
- Kurnool Project Reports 1980-1985 for the DPAP;
- tabulated records on conditions of individual 'beneficiary' wells at the Panchayat level within Dhone block.

In Dhone block, an application for 250 CI wells was submitted in April 1979, of which 208 were claimed to be at the lining stage. Subsidies of about 3,000 rupees for each of the 208 wells were released in the same month (a total of 6.25 lakh rupees). After a survey confirming only 158 wells in Dhone block, the DRDA notified an adjustment of accounts. For 158 wells, the total remaining subsidy would be 9.48 lakhs. Given the existing allocation of 6.25 lakhs, a balance of 3.23 lakhs was paid. Between September-December 1979, the BDO requested 206²⁴ oil engines, for 105 completed wells and 101 nearing completion. Release of 5.16 lakhs for the 50 per cent subsidy on these pumps was made in March 1980. In 1980, the BDO submitted that 107 wells were completed. By 1982 there was both a revised programme for FFW and a new BDO in Dhone block: the previous BDO had been transferred as a result of questions over financial management. At this stage only 57 wells were registered as completed.

²⁴ In August 1979 a review of wells eligible for new IRDP assistance meant the target for Dhone was increased to 201. After the introduction of IRDP, some community wells were transferred to the IRDP programme, although in theory the subsidy on lining was already paid. IRDP helped to bring in funds where it was proving impossible to get the original 1:1 ratio of funds:foodgrains

The new BDO requested a further release of 3.5 lakhs, but only 0.5 were released, because of extent of advances against work was still pending – in January 1982, this was 235508 rupees (almost 17000 pounds in 1982).

In November 1983, only 60 wells were recorded as completed. Table 4.13 shows the depths of excavation recorded in November 1983 of these wells. First it is important to note the number of wells for which no information exists. Then, most of the wells were not excavated to the expected depth²⁵, and so should not have cost the anticipated 10,000 rupees. There were also a number of well sites with no water level recorded, presumed dry. Among these dry wells and wells with no data, there were 38 sites where advances for lining of over 1,000 R were recorded, some with advances of the full 6,000 rupees.

Table 4.13. Range of excavation depths on FFW Community Wells, Dhone block, 1983 (Source: BDO records)

Depth excavated in wells where water has been located (m)	IRDP assisted %	DPAP assisted %
0 – 2	-	5.9
2.1 – 4	20	15.4
4.1 – 6	30.8	14.7
6.1 – 8	29.2	16.9
8.1 – 10	7.6	5.9
> 10	6.1	2.2
<u>No water level recorded</u>		
Excavated depth (m)		
5 or less	6.7	24.2
over 5		19.9
no data		7.3
Actual well numbers	65	136

Panchayat samiti and BDO records on CI wells: Dhone block, 1983.

²⁵ Many had apparently struck water within this allowed depth. It may well be that farmers would not excavate further unless water levels fell seriously; however, interruptions in the supply of foodgrains could have been a further disincentive to excavation.

On trying to analyse the accounts, the 6.49 lakhs the BDO hypothetically utilised tallied almost exactly with the subsidy for the 107 wells initially listed as completed. However, around 1.7 lakhs (11400 pounds in 1983) were missing even if all awards for lining were made, and there was still a difference between advances made to farmers and work executed of an additional 0.9 lakhs. It was impossible to follow the actual funding of oil engines, but the files on them still recorded 0.42 lakh Rupees was recorded as 'not returned by the BDO'. Awareness of opportunities for fraud had replaced any cognition on groundwater development. Indeed, the individual got away with it not just because of disbursement pressure, but because of lack of real interest and understanding about the processes and possibilities for well development. Missing funds were not the only problem. In general the release of foodgrains also was in excess of work done, although there were also sites in deficit, and sites where the value of allocation seems small for the work done. In total the work done was valued at 6.21 lakhs, against 7.42 lakhs of foodgrain disbursed.

Under FFWP and NREP work was to be executed by the 'beneficiary': contractors were forbidden to be involved in work or shifting grains. In some blocks, some cooperative organisations had executed works. However, there was circumstantial evidence of village headmen organising 'cooperative work' with a group of local labourers, with possibly less than the correct wage or food quota being paid. Field visits showed one site where villagers said wells had been developed by contractors under the coordination of the village headman, and that the contractor had paid for the work in grain, though these wells were not under FFWP. In one site, farmers said development of their wells took place under FFWP, when records said otherwise. Often farmers cited different parts of their wells as developed under different programmes of DPAP, FFWP, or IRDP, and it was virtually impossible to check developments retrospectively in the field.

Where did this leave the community wells? The more recent CI well programmes still under DRDA and SCSTC learnt lessons from FFWP. With the exception of 'social forestry'²⁶ wells, all work was later done with either cash subsidy or loans²⁷. Amazingly, rather than stopping the programme, by 1983 there was a policy that a CI well could be developed for only two people, and indeed only one if this person owned more than two acres of land! This allowed wells also to go to scheduled caste families owning this level of land in an assigned area – see next chapter – and their land ownership gave the basis for a bank loan. The unit cost to excavate a well remained 15000 rupees until 1988, subsidised almost entirely by DRDA, SCSTC and drought relief funds. On paper the bank gave credit for part of a land development package, in fact this loan worked out as equivalent to cover the pumpset only.

Requirements and practices to obtain groundwater clearance did tighten after recognition of the high number of recorded well failures²⁸. Both the banks and the DRDA started to ask for a groundwater clearance note in advance, although it was still up to the BDO to enforce this. However, the DRDA was forced to use universities and contractors besides the SGWD because of shortage of personnel (interviews with SGWD Branch Officer for Kurnool, 1983).

²⁶ Social forestry' wells included a food for work component, and some wells from both the old FFWP and the Scheduled Castes Action Plan were transferred to this programme. Excavation and lining costs were covered to one-third of the cost by foodgrains, with remaining work and provision of saplings provided from DPAP funds. For the pumpset, 33% was provided by a loan, the rest through DPAP funds and margin money.

²⁷ In late 1979, BDO's were asked to revise down their requests for lining to 3,750 R (possibly to help finance the cost of oil engines in combination with the margin money from SC/BC assistance). Thus, amongst the wells with completed lining, a cost of 6,000 R is only rarely recorded.

²⁸ The DRDA office had operated a 'failed well' allowance of 1000 rupees towards the cost of a failed well, which was to compensate for the cost of excavating a trial pit 5 metres in diameter and 2 metres deep.

Actual well development

The previous subsections all suggest unreliability of data on well development. To demonstrate this, Table 5.14 compiles together information from finance agencies and the Agricultural Census, 1975-1983. There is very little comparison between data. Numbers of well sanctioned are greater than the Census records in all blocks except Kurnool and Pattikonda. One could conclude in 1983 that administrators simply did not know the real state of groundwater development in Kurnool district – and knew least about actual developments in the blocks traditionally held to have some of the lowest well developments, and the poorest people, and where the efforts of planned interventions were ideally supposed to be concentrated.

4.7 CONCLUSIONS

This chapter has shown how the expansion of groundwater in the drought-prone area of Andhra Pradesh was driven by techno-economic networks shaped by credit and subsidy biases, rather than real scientific design. The programmes developed for the assessment of groundwater and development of borewells also used empiricist formulae and reductionist models in groundwater planning and development, that gave little recognition of any drought dimension. This happened precisely because of a lack of tradition or funding for observation in new agencies, and a 'teleological' approach to water resources analysis (where it is studied in relation to its use by the well technology being promoted). These agencies could not at first develop a reliable network of monitoring sites under their own controls, as IMD and ICAR did.

Table 4.14 Total wells sanctioned by major programmes 1975-1983, compared with changes recorded in the Agricultural Census 1976/77-1982/3

Block	Wells refinanced through ARDC/NABARD	Community irrigation wells Recorded as completed	Total	APCCADB sanctions on 'normal' loans	Total	Changes recorded in Agricultural Census
Kurnool)	306	90	396	Block		684
Kodumur)						
Dhone	774	57	831			266
Nandikothur	886	123	1009	Details		613
Atmakur	n.d	189	-			580
Nandyal	465	59	523			318
Allagadda	92	150	242			384
Koilkuntla	390	3	393	Not		18
Banaganapalli	161	18	179			94
Adoni)	806	143	949			360
Yemmiganur)				Available		
Alur	352	4	356			12
Pattikonda	49	14	63			158
TOTAL	4281	849	4941	232	5173	3477

Complied from: DRDA records, APCCADB loan records 1976/77-1982/83 and the District Agricultural Census 1978-1983

What was present was really 'non-scientific' cognitive activity, developed to suit the ideological frames present for groundwater development and the agencies to promote it. The techniques of groundwater estimation put together had neither any historically developed methodological legitimacy, nor were they that accepted by other scientists. Although focused in a DPA, estimation procedures as used barely acknowledged the drought dimension – its only influence was in using the criteria of 10% of average monsoon rainfall (of which 70% was considered utilizable recharge). Technical norms kept a focus on finding (and permitting) new water for wells to development, rather than acquiring knowledge for sustainable development of aquifers and control of well development in a DPA.

Interventions around groundwater were for better livelihood security, rather than to ensure good water management; but the science of both became overwhelmed by the administrative need to disburse funds. The programmes launched to develop wells increasingly involved subsidies as a way to bring remaining costs to a level where a bank would consider a loan. Clear warning signs - in the gap between the costs of well development and bw profitability under low yields - were never really addressed. If either well yields or profitability proved less than expected, farmers faced problems with loan repayments - and this was a risk even before large-scale development drove a decline in water levels that left many open wells dry.

Dug wells and borewells were initially of similar utility as both tapped similar water yields - but choices developed, not just around costs and water yields, but also around ease of finance for both implementers and farmers. Yield advantages from borewells only really occurred in the limestones and quartzites of the Cuddapah-Kurnool formations. Loans for dug wells remained under a more disadvantageous finance regime than borewells: indeed under special agency programmes the banks were not required to lend at

all for borewells. Borewells came to dominate, despite the problems electricity shortages: rather the popularity of borewells pushed up theft of electricity and created pressure to keep electricity tariffs low.

The two technologies were developed by different networks of organisations, and only one – borewells – had a specific form of corporation to develop it. There was a lack of coherent development of integrated authorities to ensure more sustainable water development. Divisions of responsibility between, and inadequacies of activity by, the Groundwater Department, APSIDC, APSCRIC and the SEB, all caused delays in development. Their weaknesses – together with wider funding limitations – devolved much of what could have been publicly managed development to private contractors. The Central GWB continued to push forward its models for groundwater estimation and its own exploratory programmes. This minimised any special investigations by local groundwater staff unless funded by bilaterals or multilateral donors assisting special programmes. Public funding for data collection paid for salaries rather than special investigations. Groundwater information came through operational techniques like geophysical logging and drilling, rather than scientific pumping tests. Rather agencies like ARDC, NABARD and APSIDC themselves looked to see how this data could be combined pragmatically into equations and norms: these simply soon became ‘given’. Resources for data collection and analysis came only from the DPAP. The new IRDP programme made no additional allocation for data collection, and saw 75 per cent of site selection of new wells being done by professional geologists and organisations outside the Groundwater Department.

There was thus no agency even to integrate data collection on groundwater availability and/or works executed. The agencies with the greatest impact on groundwater development were the DRDA office and the Collector, and it was their

strength in informal integration of different agencies that determined how developments took place. They managed the meetings to discuss water conditions across the year, and to them fell the appreciation of how to mesh available sources of finance, and limit corruption.

It was failure of policy to consider these problems that lay at the heart of the initial slow increase of groundwater-based irrigation in Rayalaseema, and the later extent of 'groundwater drought', rather than environmental difficulties in themselves. Failure to think about how groundwater drought could be manifested in a drought area inevitably created the groundwater drought that had natural and manmade dimensions. In Rayalaseema, the districts with the highest groundwater development success rates - Anantapur and Chittoor - were not the districts with the least environmental problems. They were the districts where a strong historic emphasis on minor irrigation had promoted a more united effort, given lack of options for large-scale irrigation development. They were also districts with a generally higher level of infrastructural development and political awareness. In Kurnool and Cuddapah, however, there was much more limited progress in minor irrigation development, precisely because of the lack of a united front among agencies still troubled by limited manpower, by lack of infrastructure, and difficulties of organising programmes against entrenched local interests. With the strong influence of large irrigation projects in these districts, interest in minor irrigation development emerged only as the release of funds pushed agencies into creating more local activity.

In 1983 there were certainly inadequate statistics by which to judge the actual extent of groundwater irrigation development in the Rayalaseema region, but the problems behind it were visible. Despite all the apparent emphasis on sustainable resource development and livelihoods in the FYPs, there was really little historical scientific

framework – or ethical framework – for the expansion of groundwater use. No coherent and realistic technical or cognitive norms evolved, and the simpler early norms became embedded in agencies as these struggled to survive. The following chapter reviews how, if at all, this knowledge and action changed with recognition of widespread groundwater drought.

CHAPTER 5

FACING DROUGHT AND SCARCITY – AGENCIES AND FARMERS IN THE DPA OF INDIA 1992-2002

Water has become scarce because every cubic yard forced to run into a pipe is a guarantee that at the end of the pipe, the demand for water will grow endlessly. Pipes call for more pipes in a never ending spiral. This is why water, less limited than ever before, has never been so scarce. Roberts, 1993 p. 4 (also cited in Mehta, 1998)

Public action is not...just a question of public delivery and state initiative. It is also...a matter of participation by the public in the process of social change. Dreze and Sen, 1989, p. 259

5.1 INTRODUCTION

By the year 2002, there had been 30 years of specific central and state planning initiatives in India for droughtprone areas. India not only experienced many more meteorological droughts, but the growing dependencies on irrigation from groundwater in droughtprone areas brought new recognition of groundwater drought in many areas. Farmers had to cope with seasonal variability always present in their groundwater supplies, which worsened in years of meteorological drought, but also was becoming generally less perennial as groundwater sources became heavily developed. Farmers sinking new borewells faced more and more uncertainty in striking economically viable groundwater resources. Thus a new debate of water scarcity emerged, now a result of overdevelopment of (borewell) technologies rather than a lack of accessible water (Ohlsen, 1987). This debate also highlighted whether public action was addressing the right processes of change, as agencies still strove to deliver old programmes and seemed unable to address the processes of environmental insecurity and social exclusion from water emerging in the DPA (Government of India, 1982; Mathur and Jayal, 1993).

To illustrate these debates and struggles, this chapter revisits the two droughtprone areas of Maharashtra and Andhra Pradesh, to review their reconfigurations as both

development arenas for accessing water, and cognitive spaces on action around drought. Section 5.2. summarises how broader debate and activism had changed ideas about best programmes for droughtproofing, as a succession of drought events brought a reappraisal of intervention frameworks supposed to combat vulnerability to agricultural drought. Section 5.3 examines the structural and cognitive changes in agencies met in Chapters 3 and 4 compared with ideas encouraged by NGOs and international donors. What is best described as 'scientific inertia' appeared present, as existing norms and routines had been refined, but few real shifts made into wider studies of the 'drought mechanisms' that act between resources and society. Technology dissemination programmes for borewells had largely run their course, and these agencies withered away under a range of problems. Section 5.4 focuses on farmers and their experiences of drought and scarcity in areas that had become dependent on groundwater. It goes behind the rhetoric of 'groundwater drought' and its physical and man-made forms, to see which wells and borewells stayed working from the programmes introduced in Chapter 4. It portrays local irrigation realities in three villages in the drought-prone area of Kurnool district, with different geologies. This section shows the capacities of ordinary people to act and build their own solutions, with their knowledge becoming socialised and embedded more through trial, error and observation rather than any scientific education.

By this time, my own preferences to work with more-farmer focused science and engineering design, and with participatory approaches, were much more developed as well as tempered by the experience of Yemen. I had moved from an instrumentalist into something akin to a 'deliberative practitioner'. My variable experiences in working with other scientists and instrumental actors had brought home to me the often political and conflictive problems in building collective cognition and joint action - but also the

importance of trying for this. The information presented here¹ is built up from informal interviews with policy makers, agency staff, grey material during a series of visits and consultancy activities in the period 1990-2002, and a longer stay in Andhra Pradesh October-December 2002, during which I undertook some rapid rural appraisals (RRA) in villages also under a Dutch-funded groundwater development project (APWELL).

5.2 CHANGING PUBLIC ACTION ON DROUGHT AND SCARCITY

5.2.1 Facing droughts: from scientific planning to dependencies on drought relief

The India-wide drought of 1987 drove the first re-evaluation of academic and planning frameworks around vulnerability under drought. Most drought-affected areas survived without famine, which brought a first rush of self-congratulation that the policies of the 1970's had worked. However, further research showed that it was foodgrain reserve management and drought relief that had prevented hunger, rather than much of the infrastructural work. By the 1990's, there were widespread assertions that adhoc programmes of drought relief were becoming prominent as a policy framework on drought², and attempts for systematic plans of droughtproofing were non-existent. Writers lamented that, as activists and politicians got more involved with drought issues, the growing political struggle and enmity fractured possibilities to build a united front on drought action. This left power with the very bureaucrats that many political writers criticised. (Ahluwalia, 1991; Mathur and Jayal, 1993; Torry, 1986). Meanwhile farmers and labourers were also participating in direct action, agitating themselves for

¹ I made a series of visits across this decade: two as a consultant on feasibility studies (one on drinking water supply in northern Maharashtra, and another with a Groundwater Training project that visited several states); and two as an observer/ researcher revisiting areas of Andhra Pradesh and Pune in Maharashtra.

² Also that these relief measures themselves were often inadequate, shaped by political pressures and connections than actual needs, and that only a fraction of relief reached target groups.

relief and water programmes where possible (Omvedt and Pantankar, 1991). By 1988 the slogan 'secure water for eight months' was on the lips of many - a demand for water that would at least supply a kharif and rabi crop. As section 5.4 shows, borewell irrigators in Kurnool felt they 'broke even' on costs if they obtained a kharif and a rabi crop.

These criticisms and actions re-focused interest in the mechanisms that linked drought and social impact, rather than just the mapping of drought characteristics. Academics and activists revisited the risk frameworks described in section 2.4.2, with writers noting that many of the older coping mechanisms of drought had disappeared, confirming that drought relief was becoming ever more important. This section now reviews the new thinking that developed in some NGO and donor-driven programmes, and examines the (limited) responses of scientific and technical agencies to transform their cognitive and technical norms as a result. Table 5.1 summarises the prominent 'framing discourses' in development programmes across the period.

Table 5.1 Changing frameworks in development practice 1992-2002

- participatory approaches, and where possible 'process projects', that emphasised involvement of people in planning of assistance and more open access to information (APWELL, 1997)
- demonstration as public action to claim perceived rights and fight apathy and corruption in agencies (Omvedt and Patankar, 1991)
- more local governance in assistance projects, bringing more non-government and informal local organisation into public action (AKRSP, 2002)
- criticism of 'green revolution' technologies, and highlighting of older and local technologies especially watershed management and rainwater harvesting (Pangare and Lokur, 1996)
- 'livelihood' and 'natural resource management' perspectives rather than a pure agricultural development focus, as problems in resource allocation and access were becoming clearer. These also increased emphasis on local organisation (Batchelor et al, 2003)
- embedding new local knowledge as core norms in a farmer-movement or even devotional practice, rather than as a scientific or expert skill (Shah, 1997)

5.2.2 Reforming development programmes, subsidies and access to technology

This consistent critique of central and state planning programmes, by special taskforces, agency audits, and academics did drive some changes into rural development programmes.

Government programmes at district level

By the mid-1990s the IRDP and some other district-level programmes had been replaced by the Swarnajayanti Gram Swarozgari Yojana (SGSY). By this time, the central government had noted how earlier programmes were pursued as separate programmes resulting in 'a lack of proper social intermediation, absence of linkages and focus on programme targets rather than substantive issues of sustainable income generation' (Government of India, 1982, p. iv). The SGSY focused on micro-enterprise generation in which a group approach was emphasised, with targets on numbers of families to be brought above the poverty line in the next five years. The activities could still include minor irrigation but general project limits were tighter³. Borewell development did not stop, but became much more difficult, partly through lack of subsidies but especially because of electricity restrictions. Public funding of wells was largely restricted to scheduled castes and tribes, for which the approval of Collector became more prominent. By the 1990s, the AP government also extended subsidies for drip irrigation systems to help spread scarce water in the DPA. However, DPAP programmes kept going, and the norms by which an area was registered stayed largely in tact (although the Central Taskforce for the DPAP forced AP to take a lower

³ For individual assistance, subsidies could be 30-50% for disadvantaged groups, to a limit of 10000 rupees. Group projects had no limit on subsidies for minor irrigation, but encouraged to find multiple credit courses.

level of irrigated area in its registration). (Interviews at Kurnool Collectorate, and with Special Commissioner for Rural Development, Hyderabad, November 2002).

Electricity supply

By 2002, shortages in electricity supply were recognised as both a curse and a blessing. At that time, supplying irrigation pumps took over 30% of electricity generated, and erratic supplies and breakdowns slowed down well development and brought uncertainty in production. By 2002, electricity supply was also under privatised companies – APTransco was the company supplying Kurnool district (there were 3 others in the state). These companies accepted greater state control over permits for new electricity connections: only 50000 were being allowed in 2002 for the whole of the state. They were developing plans to reduce illegal connections and increase 'healthy lines' by increasing capacitor banks at substations to compensate for defective components, and encouraging agricultural users to use good quality pumpsets⁴. They also hoped to introduce smaller transformers⁵ that would supply smaller groups of borewells, decreasing line length, and allowing for metering and monitoring of electricity use that could also become tools in water management (Interview with Chief Engineer, APTransco, Kurnool Office, November 2002; see also Moench, 1992; Knecht and Vincent, 2001).

⁴ These were 'monoblock' pumpsets with a standard PVC footvalve (makes frictionless), and fixing capacitors. This was difficult as farmers often felt they were the cause of a motor not running properly.

⁵ They had submitted a plan to the state for a new accelerated power development scheme to bring in these 25kW transformers. However, they saw this taking at least another 2-3 years to get passed, and find the 3000 crore rupees necessary for 13600 transformers and 4-5 sub-stations for Kurnool district.

State Legislation

Both Maharashtra and Andhra Pradesh reformed legislation relating to creation of local organisations, which made it easier for local groups to form and develop management or entrepreneurial activities⁶. However, proposed legislation to manage groundwater still could not get onto the statute book. The Central government first prepared a Draft Model Bill to regulate and control groundwater in 1970, which was revised and re-circulated to all states in 1997 (Ministry of Water Resources, 1992; Knecht, 2001). In 2002, the Andhra Pradesh government brought in a new Act – the Water, Land and Trees Act, in 2002. This proposed creating a Water, Land and Trees Authority to regulate the exploitation of surface and groundwater⁷ in the state, among other tasks, but associated with the Ministry of the Panchayat Raj, Rural Development and Drinking Water, rather than APSGWB, with the Authority calling technical experts as needed (Andhra Pradesh Gazette, April 2002). The model under discussion was for a Mandal Revenue Office in which SGWD staff would have a role (for some 6 people per district). The shift back to an administrative unit away from an expert unit was partly related to the planning discourses of the time, such a local agency was also seen as more able to integrate also these local programmes, for example all the local watershed committees that had emerged. However, this also built on local Collectorate meetings to discuss water availability and production that took place seasonally in many Districts

⁶ In Andhra Pradesh, Borewell User Associations could be registered under the AP Societies Registration Act, or the more recent AP Mutually Aided Cooperative Societies Act (MACCS), which reduce government control and allowed groups to make profits. For the MACCS societies there is no government involvement after their registration, and they organise their own elections, decide over share capital and membership fees. Banks would loan up to five times the share capital of a MACs. The activities of MACCS associated with borewells groups have included buying supplies of fertilisers and seeds to undercut retailers. They could also store harvested crops for a better price. Wellgroups were encouraged to form associations because of the many problems they can face in organisation – to help give controls against illegal connections, respond to breakdowns, and ensure rotations. NGO's could register under the Societies Act.

⁷ Existing wells were to be registered (cost 10 rupees) and permission sought for new wells (for which prior agreement of electricity connection is required). Registration was done through the Collectorate and the DRDA.

⁹ SOPPECOM is the Society for People's Participation in Ecosystem Management

(meeting attended in Kurnool Collectorate, September 1983). Some however were sceptical about placing work under the collector or administrative staff as there were no resources for the programme (Interview with Special Commissioner, Rural Development, Government of Andhra Pradesh, November 2002).

5.2.3 Alternative paradigms and programmes on water access:

The impacts of water development and agricultural intensification technologies on vulnerability and water access in the DPA generated criticisms and a search for alternatives. By the mid-1980's (and the 7FYP) there were demands for research and intervention that ensured equitable access to resources, more integrated study of both livelihood and water systems, and more conservation of inputs (especially water). These demands were hardly answered in the government agencies, but were pursued seriously by many NGO's. I distinguish three approaches that have sought to achieve ecological and equity aims rather than only productivity goals.

Community assets and access by need

Rehabilitation of village water sources – through wider watershed conservation works - but with reconfiguration of access rights to water is one of the older alternative paradigms, for example the Pani Panchayat model first promoted in Maharashtra (Pangare and Lokur, 1996). In 2002 this was seen as central to 'Peoples Action and Rural Technology (and the Council for it, CAPART), in promoting infrastructure for people built by the people, that will also revitalise a village. Creation of a collective social identity and responsibility, with locally generated tacit knowledge, seemed the more important cognitive factor than actual scientific and technical norms of water development.

Cost effective and locally promoted water harvesting and conservation technologies

NGO's like SOPPECOM⁹ had also developed low cost designs using local materials that challenged the standardised and easily defrauded financial norms of many agencies (Datye et al, 2000). These designs were available for small dams and for simple drip technology. Water harvesting technologies were often profiled as India's indigenous technological tradition: water conservation works got new emphasis under the special programme of the Chief Minister of Andhra Pradesh – Neeru Meeru – a programme to improve on water availability, and wider water conditions (Anon, 2002). However, NGOs continued to campaign against the standardised high-cost and often poorly implemented watershed programmes implemented under public agencies, putting more information for simple designs and integrated conservation works on the internet (see Centre for Science and the Environment website). In Gujarat, locally developed water harvesting techniques, constructed by wells for recharge, had spread through promotion within spiritual and religious movements (Shah, 1997; Kumar *et al*, 1999).

However, some warnings came against uncritical adoption of watershed development programmes. The DFID-funded KAWAD programme (Karnataka Watershed Development Programme) in Karnataka (see DFID, 2001) and Water Audit in Andhra Pradesh (Batchelor, 2002) questioned the continued uptake of watershed conservation work with checkdams and other structures, if runoff from watersheds was already very low. Problems included: that certain groups could capture water resources; there remained an emphasis on building structures to development water resources; they could threaten resource supply in downstream villages; new local institutions outside government were often vulnerable; and propaganda suggested quick fixes that were often misleading (Batchelor et al, 2003).

Biomass banking

Activist scientists and engineers like Datye and Paranjape (2000) had also driven the biomass framework into public consciousness. With the SOPPECOM NGO in Maharashtra, they promoted a development framework that encouraged production options that maximised biomass production under the natural cycles in an ecosystem, with a view to maximising also the employment in that habitat, rather only looking at most profitable output. It was one of the few alternative paradigms for droughtproofing couched realistically and deliberately in scientific terms. The concepts worked in the villages supported by the NGO. However, the model assumed cooperation and egalitarian employment structures hardly found in many villages. Like the other paradigms, it was dependent on an organisation to consistently support and reaffirm it.

NGO borewell programmes: SPY Reddy Wells and MERIBA in Andhra Pradesh

Fieldwork in Andhra Pradesh uncovered two additional NGO programmes for borewell development. One programme was funded by an industrialist, politician and philanthropist SPY Reddy, based in Nandyal in eastern Kurnool district, who owned a PVC pipe factory.

The intervention framework of this programme tackled head on some of the problems faced by APSIDC. As long as water potential was approved by SGWD, any farmer or group could apply, with a minimum holding of 8-10 acres: some 90-95% of wells were group wells. The programme estimated 100000 rupees as working capital for a well, but aimed to get 70-80% back. The repayment system was distinctive, related to expected build-up of crop income. Farmers paid nothing for the first two years: then paid 20% of crop income in the third year and 50% in the fourth year. Farmers were given a year free of payment, if they faced a wedding or other heavy expenditure. It was left with the farmer or group to get the borewell energised, which

was a problem in some sites visited - although some farmers had transferred their pumps and connections from failing borewells (Interviews with farmers during RRA exercises November 2002, see section 5.4).

Another smaller programme was supported by MERIBA, an NGO working in Kurnool District that was a 'sister organisation' of a larger NGO PROGRESS. MERIBA developed a programme 1991-1993 under which 10 villages were identified, borewells drilled and distribution pipes laid: 8 borewells were successfully commissioned. PROGRESS introduced alternative development models for technology transfer in land and water in different parts of Andhra Pradesh. One model was called 'Sharing of resources', also partly funded by CAPART of the Government of India, where landholders and landless share available resources. People were organised to form a *sangam* (group) who were provided with a borewell. Landowners paid 20% of income into the village *sangam*, and the money was shared between the *sangam* and wider village institutions. The model aimed to benefit landless people through sharecropping. (Interviews with APWELL staff previously working with PROGRESS, Kurnool District, November 2002).

5.2.4 Donor programmes: from expert knowledge to local cognition

Over this period, donor programmes also shifted radically. At the start of the 1990's, donors were still involved with funding larger scale technology development and expert systems. For example, in that period the UK Department of International Development (DFID) still considered funding some large infrastructure projects for drinking water in the DPAM, and funding the India-wide 'Hydrology Programme' - a major initiative in improvement equipment installation for agrometeorology, hydrology and groundwater assessment (see Groundwater department, 1999). In the end DFID funded neither, and

moved more specifically into local livelihood programmes, in which water management was a special focus (Andhra Pradesh Rural Livelihoods Programme, 2002; Tucker, 2003). The Dutch government contributed to the large Hydrology Programme¹⁰ 1990-1995 more generally funded by the World Bank. However, the Dutch also went ahead with supporting the APWELL project, which largely merged with APSIDC (APWELL, 1994). This was first designed in the 1980s as a programme for the installation of wells. Later, with scarcity problems so marked, and development discourses so changed, the programme widened to include arrangement of social and livelihood components, including the development of borewell associations and participatory hydrological monitoring (APWELL, 1999).

The Water Resources Audit and local water planning financed by DFID

By 2002, the UK Government had initiated the Andhra Pradesh Rural Livelihood Programme (APRLP), focused around self-help groups. The APRLP included local monitoring initiatives to see how user groups managed their water, and whether a village could plan its water development. Related with this programme, a Water Resources Audit was organised in two mandals – Kalyandurg in Anantapur district and Dhone mandal in Kurnool district. A specific objective of the Audit included capacity building for mandal-level water management, to promote integration of different watershed-related management and monitoring initiatives, eventually to be scaled up across the district (Tucker, 2003).

The audit consolidated and analysed all existing wells, water resources and soils data using a GIS system and an integrative hydrological model. It also undertook

¹⁰ This provided groundwater monitoring sites with automatic level recorders and wider computerisation of data records and gave a major fillip to the APSGWD in the late 1990s, see website <http://wrmin.nic.in/investment/hydrology>. (Background knowledge through my own Groundwater Mission Consultancy in 1995, for a training programme which became subsumed into the Hydrology project, see Appraisal Mission, 1996).

surveys in villages in the selected mandals on the numbers and conditions of wells tanks and conservation structures, as well as involving knowledge from experts. The audit helped to identify patterns of wells that failed in drought years, and those that did not - which was not that clearly related with geology except possibly in some granites (Batchelor et al, 2003; Batchelor, 2002). Confirming Chapter 4 in this thesis, they found no correlation between survey figures and the records of the APSGWD, or well development guidelines. They found well densities of up to 51 per hectare in one village in Kalyandurg in Anantapur, and also areas where working dug wells still outnumbered borewells, in the crystalline rock areas. I compare these findings further with my own in section 5.4. However, a core question in the initiative was whether resource auditing like this could work for better 'routine' resource planning at local level, with better interaction between local state agency sections.

Participatory Hydrological Monitoring under APWELL¹¹

The APWELL programme was funded by the Dutch government, and operated within the APSIDC introduced in Chapter 4, to promote, technical, social and environmental sustainability in groundwater development¹². Under the APWELL programme, pilot studies on participatory hydrological monitoring (PHM) developed from 1998 (APWELL, 1999), as part of a programme also assisting new group borewell development. These group borewells typically had 2-8 irrigators sharing. The PHM aimed to raise understanding among local irrigators of both local groundwater behaviour and the safe yield of local aquifers, and was offered to committees developed

¹¹ APWELL was the Andhra Pradesh Ground Water Bore Well Irrigation Scheme project.

¹² Technical – focused on well-spacing, design, yield and water quality; Socio-economic – focused on increasing income of target group, poverty alleviation and increasing opportunities for women; Environmental – focused on promoting recharge through watershed development and water quality control and water management through control of irrigation efficiency, crop choice and water demand.

for the watershed where wells are drilled under the programme¹³. While monitoring, initial training and support was done only for project borewells, meetings to discuss groundwater conditions were open to all water users. Volunteers did the monitoring. Studies were undertaken to find which measuring devices were easiest to use and what measurements best facilitated local discussions of water conditions (Knecht, 2001). The results of the monthly measurements – of rainfall, and static and pumping groundwater levels – were publicly displayed on a board in the village. The project also trained the groups on borewell operation, and hoped to prevent motor burnout by prohibiting automatic starters¹⁴ (discussions during field visits, November 2002).

Some groups also measured pump discharges in addition to the other measurements. This data allowed key PHM staff to discuss water use, extraction patterns and seasonal groundwater dynamics with villagers, often using simple examples that stayed with the listener. For example, in one seasonal meeting, a PHM worker emphasised how paddy rice required five times as much water as irrigated dry crops: thus a farmer could cultivate 5 hectares of dry crops under irrigation with the same water as a crop of paddy, which could also be more remunerative (Participation in a local PHM workshop, Kurnool District, November 2002). Farmers said as a result of interactive discussions in meetings, they could now understand how rainfall was a factor in groundwater recharge, and pumping affected groundwater levels. By seeing the difference registered between static levels and levels after pumping, across the season, farmers increasingly understood that groundwater was finite and not always fully recharged by rainfall. APWELL tried to hand over responsibilities for the PHM to

¹³ This PHM was part of a wider programme on soil and water conservation, capacity building in local organisations, and agricultural extension, through 'social organisers' and agricultural advisors.

¹⁴ The project also installed capacitors, circuit breakers and single-phase preventers in panel boards, and negotiated appropriate size of pumps for the group borewells, with this aim. APWELL created 34 BUAs, some 20 with MACCS for borewell clusters. From each borewell clusters they took 1-2 farmers and trained them for: identification of faults and pump parts; starter repairs; and checking water levels as part of PHM.

the District Panchayat Raj (PR) offices, but lack of financial resources and incentives left PR representatives disinterested in the work.

5.3 CHANGING COGNITION AND CHANGING NORMS IN PUBLIC AGENCIES

Given these widespread criticisms of public agencies, and many new local initiatives by NGO's and international agencies focusing on public interaction rather than public delivery, what actually happened in the agencies studied in detail in Chapters 3 and 4?

5.3.1 The Andhra Pradesh State Irrigation Development Corporation (APSIDC)

As Chapter 4 described, APSIDC started in 1974, but only gained wider regional capacity to assist borewell development from the early 1980's. It began to face financial problems through both its own failures to collect water rates, and in combining its own internal funds with subsidies and bank loans. It also faced delays to get borewells energised and operational in reasonable time periods. Its first financial crisis came in 1991/1992, when central refinance was needed and NABARD stopped its operation to require an audit and change of procedures. NABARD stopped the levying of establishment charges, and said all income had to come from capital works. By 1994/5 its total losses were 26.24 crore rupees. The Chief Minister also acted, not only because of these debts, but also flouting of regulatory procedures on well siting and development, and the growing groundwater crisis affecting drinking water sources. He put controls on APSIDC and the state electricity company, so borewell development slowed substantially. In 1995 APSIDC still had 2600 staff, but were forced to cut this to 850 by 1997. The state government wanted to reduce personnel to 400 people, but the union took the government to court (Business Line, The Hindu Newspaper, October

2001). From 1994 APSIDC had to turn over borewells to local user committees for their operation. (Interview with Chief Engineer APSIDC, 2000). When I met APSIDC staff in 2000, they put on a brave face to visitors on their financial and political viability, while in fact both were under question, as the state government saw decreasing reasons to keep public agencies for developing borewells.

Technically, APSIDC did change some of its operational norms between 1980, through changing resource conditions as well as the influence of APWELL. Changes included:

- An increase in drilling depth from 40-50 metres, now up to 100 or even 120 metres;
- a change from pumps of 4-5hp to 7-10 hp to cope with increasing depth;
- guidelines and actions to get electricity clearance and proper electrical installation;
- all borewells were handed over to borewell user groups immediately;
- all pumps were previously sent to Hyderabad for repair but now done locally;
- they worked with an accepted ISI list of pumps that farmers could choose from;
- they no longer did pumping tests. They registered a preliminary test at drilling with the compressor development yield, then did a simple yield test with borewell energisation.
- the criteria for a successful well was decreased from 2000gph to 1500gph.

(Compiled from interviews with the Chief Engineer APSIDC in Hyderabad, 2001 and with NABARD staff in Hyderabad, October 2002).

However, all these changes followed practical or financial requirements perceived inside the agency, and rethinking of approaches and assessment came too late with the APWELL project, whose fate APSIDC became bound up with. When this project terminated in 2003, APSIDC ceased its work in groundwater development. It remained in skeletal form, focusing only on lift irrigation projects and some water harvesting.

Borewell development models

Looking across these different approaches to borewell development – APSIDC, APWELL, SPYReddy, Meriba - technical staff and farmers gave very different views on programme approaches. From APWELL perspectives, APSIDC used to do everything individually, and also oversaw everything themselves. They did the geophysical surveys, put in the casing, lowered the pump, and chose everything including pump options. The borewell users were spectators with very little involvement. This was one reason why one person could end up dominating a group and intimidating others to leave. However, with the APWELL approach, 'beneficiaries' were present at all stages in design. They watched the drilling and could see the depth at which water was struck and flow changed. Women and men had training, in fields from maintenance to agriculture. They even talked about creating a farmers' movement rather than just operational capacity. However, other agencies also pointed out the cost problems of support to substantial numbers of specialist social organisers for borewell development.

Farmers saw key differences in relation to the higher quality of work and levels of training put up by APWELL, and their local assistance – from support to women's self help groups to initiatives in PHM. However, APWELL wells only assisted group borewells, made up from small and marginal farmers (at least in theory). Thus the SPYReddy programme did offer opportunities to a wider range of farmers, and gave quite pragmatic assistance, although it could not tackle electricity development controls. As APWELL and APSIDC ceased to exist to support borewell management after 2002, the SPYReddy model was perhaps the best of the 'special assistance' models remaining. A substantive late flowering of cognition about processes to meet local individual and group needs, with interesting participatory dimensions, faced an

uncertain future in 2002 - dependent on what banks and NGOs chose to continue. (Compiled from discussions with farmers during the RRA November, 2002, and also with APWELL staff in Kurnool district and Hyderabad, April 2000 and October 2002).

5.3.2 The Andhra Pradesh State Groundwater Department (APSGDW)

In the breadth of work presented and the appearance of its central office in Hyderabad, the SGWD seemed to have made extraordinary changes. Certainly the infusion of funds, monitoring equipment and computers under the Hydrology project, and a range of scientifically-oriented bilateral assistance programmes greatly increased its profile and sense of purpose and identity. Wider changes in legislation and the growing emphasis on water conservation also helped to increase its profile and involvement in state politics. By mid-2003 it aimed to have information in a GIS system down to mandal level to give maps of groundwater levels and conditions (Interviews with SGWD Director, October 2002). By 2001 the SGWD had its own website, and by 2003 had district maps of groundwater conditions readable on line. Additionally, the political style of the Chief Minister permeated down to at least some of the Directors of the SGWD, who began videoconferencing with their district staff (I attended one such video conference with a SGWD Director and his staff in Hyderabad in April, 2000). However, actual conditions in the district offices were often far less good. All had a computer, but sometimes only one. Conditions for storing maps and computerised information were still poor, and the budgetary stresses of annual operation still showed through. (Interviews with local district officers in October and November 2002). The quality and reliability of the information being put into the maps was also still a cause for concern.

The APSGWB still did a survey of groundwater development every two years, and submitted the information to NABARD: the declaration of development levels was even stricter in determining where banks could loan for wells. A new well census was done in 2001 in Andhra Pradesh to confirm the electricity connection, well-type, engine type and whether in use or abandoned. For the APSGWB, the task of groundwater assessment had become an important part of its social institutionalisation as an agency. However, to a substantial extent, it was external inflow of scientific knowledge and funding of equipment that allowed this furthering of legitimacy: science helping science. The new participatory forms of communication – through internet, through video conferencing, and new roles in mandal-level committees, may have helped reinforce the visibility and existence of the department, but its data was still not very reliable. In 1997, a new methodology for groundwater estimation was in place from the Central Groundwater Board (see Groundwater Department, 1999). Table 5.2 summarises the critical changes made.

Estimated total groundwater resources had increased, as a result of this new assessment procedures, and new local reconnaissance methods. Although recharge estimation changed, the unit draft allowances for dugwells and borewells remained unchanged from the Central developed norms of 1993, of 0.65 and 1.3 ha.m respectively. Borewell spacing recommendations were still 250m. In the new procedures, estimates of seepage recharge of 50-60% (including small dams and watershed) were high. Perhaps the most startling figure however, was that a 'safe' condition for groundwater was a condition of 70-90% developed, and was only semi-critical when there was already a falling trend in pre- or post-monsoon conditions. 'Over-exploited' was only used as a condition when more than 100% of known reserves were exploited and both levels showed a declining trend.

Table 5.2 Changes in the Groundwater Estimation Methodology 1997

- Continuation of a 'catchment-based assessment, but at a smaller areal level of 100-300 sq.km, but with assessments also related to administrative levels (the mandal in AP)
- Recharge assessments to be made for both monsoon and non-monsoon seasons, with a different methodology provided to estimate specific yield in the dry season, that was seen as particularly relevant to changes in the hardrock areas
- Improvements in assessment of net groundwater inflow and base flow
- Norms for return flow under irrigation were changed, to allow for type of irrigation, type of crop and depth to water table
- Longterm groundwater trends in pre-monsoon and post-monsoon levels are made an integral part of groundwater assessment
- Four categories of exploitation status were created to replace the previous three categories based on colour (white/grey/black)
 - safe a) - less than 70% developed, no water levels trends falling trends)
 - b) 70-90% developed, no trends in seasonal levels
 - semi-critical. Resources 70-90% developed, and there is a decline in one of the seasonal trends
 - critical - resource are 90-100% developed and both season levels show declining trend
 - over-exploited – resources are more than 100% developed and both seasonal levels are declining
- Observation wells were to be increased once an area came into the semi-critical category: conservation measures were to be increased when an area was in the critical category,, and micro-levels studies carried out for more correct reassessment, in critical and over-exploited areas
- It was recommended to allow 5-10% of the total annual groundwater potential to be assigned for natural discharges in the dry season
- Allocation for domestic and industrial use was to be made on population density and relative load rather than the earlier fixed allocation

Developed from Groundwater Department, 1998

That the SGWD reported no over-exploited blocks in 2002 in Kurnool district was no indication there were no problems (overexploited blocks were already reported in Anantapur, Cuddapah, and Chittoor by 1993, see Kurien et al, 1994). The Groundwater Audit in Dhone mandal found many unrecorded wells (personal communication, Audit staff, at a presentation in New Delhi, October 2002). While the framework of analysis was broadly scientific, the reliability of the data and setting of problem categories, and general cognitive objectives, were all still open to question. The APSGWD was still concerned to map groundwater that could be developed – it did not create any new tools to help in management of pumping for irrigation and other uses, nor for new allocative control of scarce groundwater resources. There was still no sensitivity to the

issue of development in a droughtprone area, nor could they give any recommendations to wells affected by natural or manmade drought.

5.3.3 IMD AND ICAR

These national agencies with such long histories of cognitive and social institutionalisation survived better into the 1990s than many of the state agencies for natural resource management and technology dissemination. IMD moved more into long- and short-term weather forecasting for agriculture, based on regional maps generated from their own agro-climatic probability mapping. They also moved more into public dissemination via television and radio, but hardly linked with agencies for natural resource management, staying with their older research networks with ICAR and the agricultural universities (Interviews with Director General of ICAR in New Delhi, 2000 and 2002). ICAR research centres continued their localised studies to find crop recommendations for the aberrant weather conditions of their areas. As the wider world of farming systems research pushed emphasis onto more work with local farmers, ICAR had engaged in more direct work with farmers, and looked at various water-harvesting methods that can both provide small local water supplies in a drought (like farm ponds). However, their scientists hardly engaged in the wider water resource management programmes active in the DPA in Maharashtra and Andhra in 2002.

Andrew Warren (1997) described the lack of interaction of natural scientists with operators on the ground as a failure of scientific paradigm – to not engage with study of the world as seen by those directly dependent on it. Several bilateral programmes did have pilot studies that involved (natural) scientists involved at local level, as in the Water Audits and PHM. However, in 2002, one still was left with the sense that

agencies for scientific research, natural resource development and local government still hardly interacted unless called together by the Collector¹⁵.

5.4 GROUNDWATER REALITIES IN KURNOOL DISTRICT, IN THE DPA-AP, 2002

This section examines the actual changes in groundwater exploitation and production output under groundwater irrigation across Kurnool district, as compared with the information and norms from public agencies. After an overview of general changes compared with conditions noted in Chapter 4, it reports on the experiences of farmers in villages in three different geological zones, recorded from Rapid Rural Appraisals (RRA) in 2002. As 2002 was a drought year with very low rainfall overall, this allowed study of how farmers were adopting to seasonal and contingent groundwater drought. Visiting different geological zones allowed examination of the real histories of farmers preferences and actions around dugwell and borewell development in a droughtprone area, and how they had interacted with agencies and accepted their norms or not.

5.4.1 An overview of changes in Kurnool district, compared to the 1983 study

Tables 5.3 and 5.4 show the phenomenal change in groundwater development 1982-2002 across the Rayalaseema region. Public records indicated 54572 wells of some kind in use in Kurnool in 2002. The electricity board noted some 49973 registered connections for pumpsets, but estimated that something like 62800 pumpsets were in

¹⁵ From 1978, the Department of Agriculture and Rural Development, Government of India, had requested that coordinating committees be developed for minor irrigation at state level, and a special responsibility was minor irrigation was also created in the Collectorate (see Ministry of Agriculture, 1979). This official supplied me with a census summary on wells during my 2002 research, which was more detailed than information accessible through the SGWD.

use - besides pumps still operating with diesel (Interview and data from Chief Engineer, APTransco, Kurnool District, November 2002). Thus under-reporting and illegal electricity connections were still problems.

Table 5.3 Changing numbers of registered borewells

Year	1982/3	1992	2002
Kurnool	148	12271	18602
Anantapur	288	14949	
Cuddapah	3047	31437	
Chittoor	1198	9618	

Table 5.4 Changing numbers of registered dugwells

Year	1982/3	1992	2002
Kurnool	14463	36397	35970
Anantapur	65452	82929	
Cuddapah	62369	44647	
Chittoor	80633	106311	

Sources: Agricultural census; minor irrigation records release from the Collectorate; a summary of mandal-level connections from APTransco; and District pamphlets from the SGWB.

The tables show that dugwells continued to be developed into the 1990s, and developed in larger numbers until as late as 1993, after which borewells did really take over. This indicates the impact of assistance programmes that still promoted wells into the 1990s despite concerns about falling water tables from the 1980s. As the remaining section will show, however, the effects of borewells were variable. Dug wells had stayed in use in the crystalline rocks. The impacts of borewells on dugwells was worst in the areas with higher groundwater yields which also attracted more public and private investment in borewells. While, by 2002, the census showed dugwell numbers declining, the number still registered was remarkable.

Numbers of registered borewells jumped enormously between 1982 and 1992, but in Kurnool at least slowed thereafter. This probably reflected electricity restrictions and funding problems facing both public agencies and farmers. Actually, across the period, the costs of borewell development dropped in real terms as the value of the rupee fell against the dollar – see Table 5.5 - although on paper official costs increased two-fold.

Average drilling costs were still only 150 rupees a metre, although pumps costs had increased (branded 5hp engines cost 16-20000 rupees, local ones 100000). Estimates of the costs of an illegal electricity connection cost varied from 2000 rupees for equipment only to around 10000 rupees for the equipment and the bribe. Formal connection costs were 30600 rupees if a connection was allowed.

Table 5.5 Average borewell development costs, Kurnool district (Source: interviews and literature survey with APSIDC and the DRDA in 1980 and APWELL in 2002, field data)

Year	1980	2002
Civil works	40900	) 122034
Mechanical and electrical works	22400)
Charges	15203	24007
Total	78563	146041
Costs in real terms US\$	5337.33\$ (1\$ was 15r)	3074.5 \$ (1\$ was 47.5r)

In 2002, information on groundwater development was available only for 1993 - the SGWD was still processing data to give the situation for 1997 (i.e. were more than five years behind). Nevertheless, the available data was startling. Possible numbers of additional wells in 1993 were substantially greater than in 1983, despite an almost 10% increase in level of existing development. They were also two times again the number of wells the electricity board thought already installed.

	1982 % status of development	Possible number of additional wells and pumpsets	1993 % status of development	Possible number of additional wells and pumpsets
Kurnool	9.31	61404	18	104116

(Kurnool district pamphlets produced by SGWB)

These remarkable figures from the SGWB were said to reflect better methods for assessing groundwater availability. In 1993, it still had no blocks designated grey or black. In 1998 only 9 of its 54 mandals (sub-blocks) had groundwater development levels registered above 30%. Only in late 2002 were 2 mandals registered as 'black' (over 70% developed). None of the villages reported here were reported as even in a

semi-critical stage, though some had seen problematic declines in water levels¹⁶ and yields. A private borewell contractor estimated that the average depth of borewells in Kurnool District had increased from approximately 53 metres in the late 1980s to some 84 metres by 1999. In some areas it was now 100-120 metres (Knecht and Vincent, 2000; field surveys).

Another surprise in this study was the stagnation in irrigated incomes under crops promoted in the 1980s. Table 5.6 shows that several of the traditional 'irrigated dry crops had declined in value in real terms, and that the profit now was more in horticulture crops - citrus and mangoes as tree crops, and okra and chillies as ground crops.

Table 5.6 Gross and net margins of crops per acre under irrigated production (rupees)

Crop	Gross income 1982	Gross income 2002	Net incomes (a)
Groundnut	3000	6000	
Sorghum	2500	3000	
Ragi (Finger millet)	1500	3000	
Vegetables	3000	8000	Okra 5000 (a)
Fodder	4000		
Grapes	20000		
Citrus	10000		
Mulberry	8000	8000	
Finger millet, cereals		3000	
Gram		10000	7000
Paddy		20000 (a)	15000 (a)
Sunflower			7-8000 (a)
Cotton		10000	
Mango/sweet orange		15000	15000 – 50000
Chillies		12000	Green 9000 Dry 20000
Commercial crops (average cotton and groundnuts)		8000	

Source: APSIDC for 1980 data, APWELL for gross 1990 data (a) from farmers in field research

¹⁶ Reports on the declining water table depths varied. Development agencies had to rely on the wells monitored by the Central Groundwater Board. In 1993 these indicated falls of only some 0.6-2.0 metres across Kurnool district – although figures showed up to 12 metres in parts of Anantapur (Kurien and Dhoolappa, 1995).

As before however, the most profitable crops – okra, chilies, and paddy - were also crops that needed more working capital for inputs. In 2002 the government was subsidising sunflower (60% of seed costs) and fertiliser for groundnuts. APSIDC staff estimated that the income from a borewell had increased from 4000 rupees per acre in 1980 to 6-7000 rupees an acre in 2002 (although APWELL were claiming it could be up to 15000 rupees). In real terms, however, this was not a major increase, and in the 1980's there were no electricity supply problems. Borewell development was beginning to lose some of its attractiveness as a droughtproofing tool for reducing vulnerability, unless relatively low groundwater yields could be matched to one of the profitable crops like paddy or tree crops.

The table also shows that few crops could compete with the income available from rice production, even if it was 'banned' officially in publicly assisted projects. Apart from its incomes, rice is the staple food crop, provides fodder after harvest, has lower labour requirements than cotton and can withstand high intensity showers much better than the 'irrigated-dry crops' like cotton (Knecht and Vincent, 2000).

Although many areas were experiencing groundwater yield decline across the season by 2002, farmers in all the sites used a similar rule of thumb. If they cropped in just one season they covered their production costs: a second and third season was pure profit. Increasingly however, a third season was impossible as groundwater was insufficient. If wells were working, they at least gave some assured income. Unreliable power was a major concern alongside declining groundwater resources.

Table 5.7 synthesises key data on patterns and levels of well and borewell development in the three different geological regions now reported on in detail from RRAs undertaken November 2002¹⁷ (the names of the villages are not given, to give some anonymity to those who gave time and comments to the exercise). These showed considerable variations in actual patterns of over-development and uncertainty, despite the prevailing discourses of man-made drought and over-exploitation on the one hand – and ‘non-critical’ conditions given by the SGWD on the other. The highest levels of well and borewell development had occurred in the regions also considered to have the best resources – the Kurnool-Cuddapah system tapping quartzite and limestone – in the eastern district.

In central Kurnool, geological conditions had traditionally given little scope to dug-well development, except in very favourable limestone water table aquifers in basin sites. Here too there was a mixed history of expansion of dug wells and borewells, with equally mixed development of new levels of groundwater drought as borewells operated increasingly short seasons in some locations.

In western Kurnool, under the crystalline rocks, traditionally a zone of dug wells, open wells had not only expanded in number, but some had survived in use (thus confirming the experiences of Batchelor et al, 2002).

¹⁷ These RRAs involved both discussions and the schematic development of maps that showed the location of wells and became the basis for discussion of timelines of well development, and differences in yield in space and time, as well as different borewell assistance programmes. Villages were selected after discussions with local NGOs working in the three different regions, and preliminary visits where we asked farmers if they would take part, and a time was fixed, and some general information was also collected. Evening and day visits were possible, at the convenience of farmers. While some appraisals took a day or two, one longer appraisal of one week with field visits and repeat evening discussions was set up in central Kurnool district. All borewell users were asked to attend: the number participating however, typically 10-20 farmers, usually male. Women sometimes attended evening meetings.

Table 5.7 Numbers of dugwells and borewells in study villages in different geological zones (figures in brackets show number of wells still in use)

Village and geology	Dugwells Pre 1980	Dugwells 2002	Total Borewells	APSIDC	APWELL	SKREDDY	OTHER
EASTERN KURNOOL Quarzites, limestones, shales (highest yield zone) KRP	58	109 (5)	140(61)	ND	ND	ND	ND
CENTRAL KURNOOL Limestones, sandstones		Hill transect					
KP-K (highest village)	?	25 (?)	80	2	2	50(25)	30
UY	0	0	180	8	12	0	160
KG		13	62	4	15	13	34
UP Limestone	10	180 (0)	300 (50% seasonal)	4	0	70(30)	225
LD (base of foothills) Weathered shales and limestone		5 (0)	150 (110)	17 (16)	22	0	71
WESTERN KURNOOL Granites, crystallines PT	100	300	15		4	0	10

*from Knegt 1999, other data field research RRA November 2002.

5.5 WELLS AND LIVELIHOODS IN EASTERN KURNOOL DISTRICT

This zone of sedimentary formations – in the ‘Kurnool-Cuddapah’ geological series with cavernous limestones, quartzites, phyllites and shales - proved to have some of the highest groundwater yields and borewell development in the district. Although there were dugwells present traditionally, this area was a focus of massive expansion of borewell technology, especially also as techniques developed for better assessment and development of borewells in these rocks. Yields of 5-7000 gph were common. Originally drilling was only to 30m but by 2002 farmers drilled to 90-100m. Two visits and meetings were carried out in RKP village (including attendance of the PHM workshop nearby), that was also studied by Knegt (1999) and reported in Knegt and Vincent (2000).

Knegt (1999) compiled the following history line for well development.

Period	Dug well numbers in use (cumulative)	Borewells in use (Cumulative)	Depth of drilling
1950-59	8	0	N/A
1960-79	58	0	N/A
1980-89	65	13	23-61
1990-99	76	110	49-61
1999	5	130- 40	43-76
Not in use 1999	104	79	

Dug wells expanded from the 1960s as pumps came into use. Borewell development expanded heavily after 1990, as special assistance programmes moved into the area. The irrigated area was estimated to have increased from 160 hectares in the late 1960s to around 400 hectares by 1999 (APWELL, 1999a). The SGWD estimated that annual groundwater extraction in the larger area surrounding RKP was less than 70% of annual groundwater recharge – based on data from four regional groundwater observation wells, the nearest some 6.5 kilometres north of RKP. However, based on local and more detailed information, APWELL (1999a) estimated that groundwater exploitation

in RKP exceeded 110% of recharge. Since 1999, no new dug wells were constructed, and open wells were largely abandoned. Borewells, however, were still being established. On the basis of participatory rural appraisals, APWELL (1999, pp. 11) estimated that the average pre-monsoon groundwater table stood at 6 metres below natural surface in the 1960s, and at some 15 metres by the late 1990s. Feedback from farmers gave anecdotal evidence illustrates a progressive depletion of local groundwater resources - see Table 5.8.

Table 5.8 Evidence of declining water tables (source: Kengt, 1999; Knekt and Vincent 2000)

Farmer E. saw his borewell yield decline from 72 m³ per hour to 36 m³ per hour between 1994 and 1999. He could be this exact as he occasionally supplied water from his borewell to tankers, and measures the time of filling.

Farmer T. explained how he and his brother lowered their pump in stages from an initial 9 metres depth to 33.5 metres between 1988 and 1999.

Farmer R. reported that in 1985, a contractor drilled his borewell to a depth of some 67 metres. Until 1997, he irrigated one hectare of crops such as groundnut, cotton and paddy using a suction pump. Then discharge declined, and an upper section of the bore was excavated for some 10 metres like a well, to install the suction pump at its base. The discharge sufficed until 1998, then again declined, so a submersible pump was installed. Since then the pump had been lowered several times, and now hung at the bottom of the bore. The borewell was now dry.

Knekt (1999) found that irrigated farming gave an annual net return of up to 2,000 rupees per acre more than rainfed farming. Irrigated cotton was more profitable than paddy (some 6,500 rupees against 3,000 rupees), and than irrigated groundnut or sunflower.

In RKP there were 12 APWELL borewells, with yields ranging from 3600-8100 gph, getting power for agricultural use for 4-5 hours a day – at night. An acre would take 1-2 days to irrigate, depending on crop and soil type. Typically a farmer had water for two days, and with the small size of group per well usually got water every seven days or so. The borewell user association was registered as a MACS. Apart from managing the borewell, being a MACS enabled the group to buy inputs wholesale

(seeds and fertilizers for local resale. They had also started a self-help group which supported members with credit for new activities like milk cattle.

Before, villages asserted they could get only one crop, and had faced drought 3-4 times in last 10 years. In 2002, with a borewell, they were confident to get two seasons - however in APWELL borewells they could irrigate as little as 0.5 acre under a summer crop. In the recent drought years, they had not irrigated in kharif. They cropped in rabi (usually an ID crop and sometimes still some paddy) or sowed a late gram crop, usually on a smaller area than would go under irrigation in kharif (when rainfall might supply some water).

The eastern zone of Kurnool district had experienced the classic 'pumping race' and disappearance of open wells as a viable technology. The borewells, where they survived, still gave a better and more assured income: however declining profit margins and production problems with some irrigated dry crops had changed crop choices and indeed made commercial production choices more risky. Villagers had developed their own norms to cope with drought – both natural and manmade. They now aimed for two seasons of cropping rather than three – an option wiped out by borewell interference. In a drought year, they operated the borewell in rabi only, based on pumped yields available, and cultivated smaller areas.

The enforced transfer of borewell management to local groups had worked in this case of RKP village as they came under a participatory model by APWELL, to create a multi-purpose organization which could oversee operations and maintenance and bring in some added attractions in help with supply of inputs, credits and marketing. The work of the APSGWB and the GEC had been largely irrelevant, and no local actor saw the newly proposed mandal water committees making much difference to their operations. (Interviews during field visits to RKP, November 2002).

5.6 WELLS AND LIVELIHOODS IN WESTERN KURNOOL

In the west of the district, with its crystalline rocks of granites and gneisses, groundwater came from a shallow water table aquifer 50-60m thick, with the main fracture zone holding water only 35-40m deep. This was a zone that traditionally irrigated with dug wells, and its geology gave little or no major yield advantages of borewells over dugwells: in fact dugwells could provide better supply through their reservoir capacity. This subsection reports on one village PT, some 20 kilometres from Adoni town in the west of Kurnool district, very close to the border with Karnataka. Despite the problems of falling water tables, the field study in 2002 still found dug wells and dug-cum borewells in use.

PT village was still listed as a DPAP village, although its current levels of irrigated area took it above the limit for a DPAP village. It was located across a basin, surrounded by hills. The physiography gave a difference in recharge patterns and groundwater yields, and thus cropping options between wells in the basin floor (where the main village is sited) and on the hill slopes. These ecological differences were echoed in agrarian differentiation, with the marginal lands on the hillslopes largely occupied by Scheduled Caste farmers. Its village area was just over 4000 acres, of which some 1500 acres were irrigated – some from a large tank (irrigating some 100 acres under paddy) and the rest under dugwells and borewells. Villagers estimated they needed three acres of irrigated land to work fulltime in agriculture and support a family.

Recharge in this basin was influenced by seepage from the tanks and a minor canal of the Tungabhadra (Low Level) irrigation system which passed through the village area, although no part of the village was irrigated by it¹⁸. Villagers thought some 50% of open wells in the basin area benefited from tank or canal seepage. They also thought

¹⁸ Possible recharge has reduced since the canal was lined. Villagers say water levels in wells dropped visible after lining in 1995 - however the poor state of the banks means some seepage must occur.

the forests on the western slopes increased the rainfall. Some areas had had checkdams built on them, which villagers thought had made a difference.

Villagers estimated that in the 1960s there were only some 40 dug wells, tapping a depth of 15-35 feet. By the end of the decade 1971-1980, there were some 100 dug wells, some 40 of these from the Scheduled Caste Corporation, which then cost 9000-17000 rupees per well (the standard norm in Chapter 4). The number of dug wells rose again 1981-1990, to 130, and by 2002 there were estimated to be some 300 dug wells. Of these 100 had been financed by bank loans¹⁹. Only 4 came under the DRDA programme (the million wells scheme), which had a cost of 27,000 rupees. Of the 300 open wells, 120 were still operated by diesel, and 180 by electricity, typically serving 5-6 acres: 25 had an inwell-bore now tapping to 60-150 feet: villagers estimated this doubled the yield. Also, some 200 wells were 'group wells', with an average of 3 people involved, based on joint families sharing. Wells in the basin area were said to fill back within 18 hours. They estimated 2 days to irrigate an acre. People did cite costs as the main disincentive to new dug wells – the last finished open well was dug in 1995. It took 10 labourers two months, and cost around 50000 rupees (930 pounds). However, a new well had been started a fortnight before the interviews in 2002, using a digger for the first time in the area – they were digging to 20ft, and it cost around 20000 rupees. A borewell was estimated to cost 15000-25000 rupees for 100 metres, apart from the costs of the electricity connection and pump, adding up to about 80-90000 rupees (cheaper than APWELL and APSIDC as this involved no other establishment charges in laying out pipes etc).

In 2002 there were some 15 borewells. There was only one farmer with a successful borewell before APWELL borewells started in land in the neighbouring mandal (most

¹⁹ from the Rayalaseema Grameen bank and KDCC. For a bank loan, farmers needed to have five acres of land, have a bank book, and paid 15% interest.

of these APWELL borewell users lived in PT village). Two APWELL borewells drilled had been failures. Despite the relatively low borewell numbers, spacing was still less than 100m apart and it was common to see neighboring borewells pumping at the same time. Borewells here often had a 'storage' tank at ground level (some 758 gallons), not only to protect against electricity breakdown but also to provide head for irrigation. These tanks were filled at night when there was electricity. They also relied on only two seasons of cropping for their livelihoods, with only 0.5 acres cropped in summer as a norm. Most wells supported 'Irrigated Dry' crops or vegetables grown traditionally in this area of 'less potential groundwater', with paddy grown mainly near the canal area. Only with some special support could small farmers move easily into newly profitable tree crops like papaya and mango.

Villagers thought that the area was fully developed for borewells against water available in a dry year, although it was not listed as over-developed by the SGWD. What has helped preserve such a large number of operational dugwells? Villagers said a big factor was poor electricity supply. Many feared that if farmers did switch to borewells there would be a major decline in levels and yields, although they were interested in borewells.

Table 5.9a-c gives narratives from different well groups visited, in different sites and assisted under different programmes (compiled from RRA in PT village, November 2002).

Table 5.9a Dugwells in the basin - farmer ‘Ahmed’

He had a partly lined dugwell, developed from the ‘million wells scheme’ of the DPAP (there were four in the village). He got it over other applicants because of the way he helped officials and there were political pressures that helped him. The well construction took 10 men and eight women 1.5 months to dig. His father was a labour organiser, coordinating up to 100 people. An elder gave him advice on where to dig. He used the well with his two brothers: together they had 7.5 acres in total and he had 5.5 acres. He grew 0.8 acres of paddy, and otherwise irrigated vegetables. He also grew unirrigated cotton. He had had this open well for 13 years, and he could pump it for some four hours – he estimated there was usually about 8 feet depth of water. The pumping depth was 25 ft. He employed a teenage labourer (16 years old) who he paid 30 rupees a day and also supplied food and clothing.

Table 5.9b APWELL borewell cluster (close by PT village)

While men have been the main applicants, wives can be co-applicants and women could apply in their own right if they owned land. In this borewell cluster there was one woman with three acres under her own name as an only daughter who inherited land, but her husband worked the land. Water was rotated every two days per person, and the rotation continued regardless of whether the person took water at their turn. These farmers grew groundnut, cotton, sunflower and chilies, and also some had papaya and mango trees. Before the borewells they only cultivated one crop: now they could often crop through to the summer, although they only cultivated 0.5 acres each in summer. Participants stressed how it had changed their lives and created wider employment. One borewell user had three acres planted under papaya, which she currently intercropped with chilies and had employed up to eight people for weeding. Agricultural wages were still 20-25 rupees per day. In farmer numbers, these APWELL group borewells had 3-5 members.

Table 5.9c Scheduled caste dug wells on the hill slopes (literally beyond the (rail) tracks)

To reach these wells, one traveled up the hillsides, across sandy wasteground some 5 km from the village centre, onto much poorer soil on the slopes of granite hillocks, which were exposed, with a drying wind blowing much of the time. None of these wells were lined. Of the 100 acres in the area, some 30-40 was irrigated. Of the wells dug, several have failed. Farmers said these wells began to fail 10 years ago, after only working two years or so. Some farmers said they paid off the loan but kept their motors in hope. Some wells continued to work but only supported a small area e.g. just one acre of chilies, because the yield is so low.

Farmer 'Narsimha'

Narsimha was a Harijan, and his well was 22 years old. He had seen water levels decline since about 4 years ago – it had dropped by 4 ft – and he thought this was due to lack of rain. His site was selected with a resistivity survey. The well was 20 m x 20 m, was 20 deep in grey weathered rocks, with about 5ft of standing water in it. The well was sanctioned for 5 farmers, but he was now the only actual farmer (his father was alive but old). He took a loan for a motor costing 16000r overall but because of subsidies he paid only 1800 rupees. This 5hp Subima motor was still working, although he'd had it repaired 4 times – this cost about 2000-2500r each time in Adoni. Some other farmers had to take full loans. At that time there were no restrictions on electricity and he got a free connection. He now got electricity for six hours a day. As his well seemed to be failing, he wanted another (bore)well. He was irrigating 3 acres, and growing sunflowers and chilies - but thought there was really only enough water for 1.5 acres to be irrigated properly. He laid out his fields with bullocks and did not use tractors. He sold the chilies he grew in Karnataka, grouping together with 4-5 other farmers. He had 16 acres of land overall, but recently sold four acres of dryland to buy medicine for his sick son. He sold this land to another Backward Class farmer – some 60 acres of the area had been sold to the Walmiki Backward Castes. He had six children and had to spend on their marriages. His family worked fulltime in farming.

Farmer 'Busamma':

His well was also 22 years old. It took 15 people forty days to dig. The two sons of Busamma operated it: it had to support eight family members. When the well was first dug they could irrigate 4 acres, now yields were declining and they could only irrigate one acre – they had 0.75acre of chilies at that time. They had hoped for a 0.75 plot of paddy but they could no longer irrigate this. They had four acres total, they were growing (unirrigated) kharif cotton, getting 8-9000r/a/yr. They also had livestock. They thought the problem of falling water levels might be due partly to decline in rainfall but was also due to siltation of the well. They did not desilt as they saw it as too expensive – around 1000 rupees cost. They said they got no subsidies for development, and saw no help from officials who they found rude and dismissive. They were in a self-help group supported by the DRDA, they thought the watershed work was OK, and saw its value when it rains.

In contrast to the experiences from the central and western zones, open wells and ID crops had survived in this 'less potential' zone. The wells developed under programmes of the DPA – in group wells under DPAP and SCST assistance, and individual wells under IRDP – were all still working. However, there were also many of the problems highlighted from the last chapter. Most group wells were in fact family wells, and community irrigation wells were on private lands. While many of the farmers cited costs for wells equivalent to the norms of the last chapter, it seemed that at least one well owner Busamma did not get the assistance he should have done in developing the well. No dug wells had lining or a parapet, (to reduce costs) – one of the reasons also for siltation problems. The work of the APSGWB was largely irrelevant to the dynamic of changes in well numbers. For borewells, only the APWELL programme (and not the older APSIDC) had any influence, perhaps because they looked beyond the 'norm' that this was not an area appropriate to borewells. Their wider support and advisory work also helped some farmers to expand into more costly and risky venture like papaya production. Otherwise, farmers in this village of very mixed caste and religion actively participated in their own social networks in the search for better livelihoods. On the more marginal lands, experiences of dugwells had been more variable: some had failed but others survived to support chilies, sunflower and cotton production. Again, farmers had started to develop their own norms for groundwater drought- they aimed for two seasons only, and adjusted their irrigated area to the yields they saw from their wells. While they welcomed advice and help with cleaning and revitalization of their wells, there were no advisory services for this at the moment. For borewells, they had adopted storage tanks as an additional technology useful against electricity and yield fluctuations, but again this seemed mainly under subsidized borewell programmes. So far, no drip technology was in use.

5.7 WELLS, LIVELIHOODS IN CENTRAL KURNOOL DISTRICT

Central Kurnool is underlain by the sedimentary formations of the Lower Cuddapah system: usually quartzites and shales with some layers of limestone, which are overall less predictable to develop than in the eastern zone. It has weathered and fractured zones that again give some better yields. Its hilly terrain also influences the spatial geography of water movement, and some of the worst problems of drying borewells were occurring in the foothill zones. At the time of the 2002 RRA in November 2002, no agencies had developed any mapping techniques to monitor such spatial interaction between village groundwater abstractions. An RRA was performed across in Nannur revenue circle, some 20 miles from Kurnool town, to study a transect of villages across the hills 'uphill' from Nannur – a village seriously affected by drying up of even its drinking water borewells in summer. By 2002, the area was dominated by borewells, but had seen very different trajectories of dugwell development 1985-1995. The proximity of the site to Kurnool, and the nature of the aquifer formations also meant that there were several borewell development models to study - old APSIDC borewells and SPYReddy wells, alongside borewells drilled privately and by APWELL. Findings from four villages are reported here, that were successively higher in the massif - KG, UP, UY and KP. This allowed some insight into different and interactive groundwater dynamics and the understanding of villagers of them.

LD Village

LD village covered a broad fan of land sweeping down from with two arms of hills. The slopes, with red soils, were under dryland crops. but otherwise it had black soils. Of some 1000 families, 500 still farmed: around 50 farmers had more than 10 acres, and about 150 had less than 5 acres. Around 1980 there were only 250 farmers, and 1

farm was 100 acres (the same family as the current largest one with 30 acres). Of the rest, some 400 families were labourers and the others were businessmen or had government jobs. LD was less than an hour by bus to Kurnool town, and close to the main road also. There were some four families with children in the US, and some 20 families with children in post-graduate education.

The cultivated area was about 2500 acres, of which 32% was irrigated, taking it above new DPAP criteria. Groundwater appeared in two pockets, and some farmers had only dryland. In 2002, irrigated land was valued at some 50000 rupees per acre whereas dryland was 20-35000 rupees per acre. To rent, irrigated land with a well of its own was leased at 5000 rupees an acre: it was 3000 rupees if under a group borewell. Dryland was rented at only 1500 rupees per acre. Before the borewells, rainfall was the main water source for most farmers. There was a tank, but this breached in 1939: although repaired once, it now no longer distributed water (an APWELL borewell was close by). There were only 3 large dugwells in the past, that could irrigate up to 7 acres each, but they had water throughout the year and were all with large farmers. They dried up after borewell pumping started, and had now silted up or collapsed. Unlike elsewhere, there was no interim expansion of dug wells here, perhaps because the geology was challenging.

Electricity arrived in the village in 1968, and was first used in agriculture in 1970²⁰. The first APSIDC borewell came 20 years ago. Four borewells came in the 1980's, and one of them could irrigate 20 acres; only two of these were still working. Between 1980 and 1990, about 30 private borewells came up, then another 120 borewells since 1990, giving 150 in 2002 irrigating some 800 acres. The larger farmers could have 2-3

²⁰ In 2002 farmers got four hours of 3 phase power for agriculture in the night. Opening the outlets and switching on the pump was the responsibility of the next person who would be up at 0200 hours in the morning. There was no automatic starter allowed here. They paid on the slab system: twice a month they paid 354r for 5hp and 500r for 7.5hp engines. Meters were supplied to register for a unit charge (50 paise per kw), but they were not connected. The bill came to the registered landowner.

borewells in their holdings. APSIDC borewells came in batches, one time five, the next time six etc, and there were 16 IDC borewells still operating, as one had collapsed. Except for one group well of 7 acres, all other APSIDC wells were registered to groups of 9-10 acres. Of these 16 APSIDC wells, four now had water only in kharif. The rest still worked – but only three still functioned as group wells. The rest were now all with an individual family. APSIDC records showed the borewells drilled into weathered/fractured shales and limestone, meeting hard limestone some 60-90m deep, after which no water could be found, and farmers knew this geology for commissioning new borewells. (Interview with APSIDC staff, Kurnool District, November 2002)

APWELL drilled some 26 borewells of which 17 were successful, electrified since 1994. These served four families on average and irrigated close to 10 acres per well. Some 15-20 farmers had redrilled their borewells since APWELL started drilling. The current pumping yields of APWELL borewells were still quite low overall:

Yield Range gph (irrigable area in brackets)	Pumping yield % wells (numbers in brackets)	Drilling yield % wells (numbers in brackets)
Failed	34 (9 out of 26)	34 (9 out of 26)
Less than 2000	23.5 (4)	47.1 (8 of 17)
2000-4000	52.9 (9)	47.1 (8 of 17)
4000-6000	5.8 (1)	0 (0 of 17)
6000 – 6600	17.6 (3)	5.8 (1 of 17)

(Source: APWELL borewell drilling records, 2002)

With a working norm that 3 acres of irrigated dry crops needed 1000gph, there were clear stresses coming onto the group wells that had under 2000gph and a potential group area of 9-10 acres. These were also yields in the early days of the borewell. Villagers admitted there had been problems sharing water, particularly when two or more farmers wanted water at the same time, and when individuals sold water to other farmers. Private farmers did sell water to adjacent farmers if they had excess – the

charge was 400 rupees for two days. About 60 farmers did this. There were no spacing controls on borewells.

The APWELL borewells did have an 11-member borewell committee (Borewell User Association, BUA) that met as necessary. It had representatives from all the borewells, and one women representative. They had managed problems of motor burnouts on almost all the bores – they got then rewound/replaced in Kurnool town, at a cost of 200 rupees. The BUA was concerned about technical support after the APWELL project ended, mentioning the need to flush and clean borewelllls specifically. In addition to the BUA, the village has several micro-credit groups.

Farmers recognised that there is variation in well behaviour across the year, also across the village area. The largest drop had come in the western area (downslope from UP village, which had large-scale well expansion and now had a zone of seasonal wells). Here nearly 20 wells were dry by the end of the March. The eastern zone was mainly private wells and one there is dry.

How did farmers cope with what they also saw as more uncertainty in a drought year? Farmers differentiated on the yields seen. If yields were low, they grew sunflower, okra and went for horticulture and vegetables. If better, they went for chilies and groundnut. If pumped yields were high, private wells grew paddy. If groundwater yields were low continuously, farmers seemed interested to plant mangoes because of good prices - farmers grew crops like sorghum for fodder while the trees established themselves (value 3-400 rupees per acre as fodder). They stopped cotton two years ago because its pests were infecting all crops. They had a crop rotation: sunflower/chilies/groundnut and intercropped groundnut and sorghum, and red gram and sorghum. If wells still had water in summer, they put only 25% of the area under vegetables and left the rest fallow.

Irrigators here had seen their groundwater levels declining, and they understood its links with rainfall now. If rains were good, all 150 wells could pump through for a summer crop, although they may only be able to irrigate 25-50% of their area in summer. If rains were poor then even a rabi crop was not possible on 50% of wells. As 2002 was a drought year, they were still anxious about the Rabi crop. There was one well where a sprinkler system is used on part of the land, assisted under APWELL²¹.

How then did the different well programmes compare in their impacts? The next two boxes give a brief overview of their different experiences of development under the different assistance programmes and technologies. These profiles show that overall, this village had benefited from borewell development: older borewells still worked, even if the area supported was decreasing. While some borewells were losing the summer crop option, few had dried up, or were only seasonal. However, these borewells, that were supposed to be an antidote to agricultural drought, were suffering more from seasonal groundwater drought. Comparing LD with concerns of Chapter 4, it is clear that many APSIDC wells did go to larger farmers. Also most APSIDC borewells, even if they started as group wells, were under one family or owner. The only borewell really functioning according to the original equity design was that with a group of Scheduled Caste irrigators – members of which were now active in several other development initiatives including micro-credit. APWELL borewells survived, but not without problems. The KPYReddy well may have lost group members under caste politics.

²¹ This land is with the ex-president of the BUA, who was helped via APWELL: he is the only farmer with such a kit. The overall cost was 12000r and he paid 9000, with 3000r subsidy.

Table 5.10a Status in 2002 of APSIDC BOREWELLS drilled in the 1980s

Borewell 1 Five Scheduled Caste farmers got six acres of land ceiling land -they grew paddy, groundnut and onion. The small families had stayed with this well. For the first ten years the water was excellent – even sufficient in summer but now it dropped back in summer. It was 20 years old, 8 acres, and had 10 members (although 2 parts were affected by death of cultivators whose children are not interested). Each had 0.8 acres. The well had run since it was turned over. However the motor had burned out three times, and once the motor fell in the bore. They split the cost up in relation to area cultivated. The water level did decline after March so they only had two crops. They had no committee as there were no problems that could not be solved as they came up. The command area was 3 parts onions, 2 parts sorghum, 1 part paddy, 1 part tomato, 1 part sunflower and 2 parts fallow. They organised turns 1 day per person, although this could be a bit of a problem for the paddy grower. They saw no problem: people needed paddy for home consumption and fodder. One of the cultivators worked additionally as an agricultural worker (50% on her own plot, 50% off farm): she grew onions to sell in Kurnool, She was also a group leader under the UNDG Self Help Group programme – and network president. She thought you needed 3-4 acres for irrigation for it to be profitable (it would be 20 acres for rainfed crops).

Borewell 2 : This borewell was some 15 years old, and there was only a single farmer from a higher caste. He applied under different family (binami) names. He had 16 acres of land. Part of the land was under onion and paddy. Across the river was a patch of land once supposed to be under this well, where the farmer has since drilled his own well to irrigate 2 acres. Informants said the same family had another borewell supporting 14 acres. At that time the family lived in Kurnool and leased out the land for 4000-5000 rupees per acre. This was a powerful family once considered village elders.

Borewell 3: This borewell originally had three members irrigating 18 acres. There was now only one, who leased out land and water. The family no longer lived in the village. The farmer had 6 acres for irrigation, and paid 25000 rupees for this, and leased in 14 acres overall. He employed eight people to harvest three acres of onions at the time of interview, and was also growing specialised crops like chrysanthemums and curry leaves. He also had a nursery plot for aubergines, onions and chilies.

Borewell 4: This borewell once had three brothers irrigating 10 acres: now there was just one, and it had been individually run for 10 years.

Borewell 5: This borewell had been two brothers only from the start. It originally supported 17 acres, but now irrigated 10 acres. They were growing one acre of paddy.

Borewell 6: This borewell now had only one farmer with 10 acres, who was leasing out 5. He bought out the other owners (three acres) by paying them 70-80000 rupees.

Borewell 7: This borewell was originally 10 acres, originally five members. All others sold to one person, for 72000 rupees.

Borewell 8: This borewell was originally five people, but now only one person.

Borewell 9: This borewell was now seasonal, with only one farmer, but he could irrigate up to 18 acres in kharif.

Borewell 10: This well was 20 years old: there had been three farmers in one family cultivating 25 acres. The original borewell had declined, and another had been drilled.

Borewell 11: This was a failed well (in an unpromising place). The site was then under paddy (flooding naturally). There were originally two members: both now have other wells.

Table 5.10b Status of APWELL AND KRYREDDY BOREWELLS

APWELL borewell by tank: this had 3 farmers, on 7.5 acres. They grew wheat, groundnut, chilies and 0.5 acres of paddy (flooded area). Actually 2-3 acres could get flooded sometimes. They used to rotate water on basis of need but they had now switched to a one day per acre rota. They had had conflicts - problems of people being accused of taking too much water, as well as members wanting water on the same day. Rotation: 3 acres had five days: for paddy the farmers take water when they want.

South of hills

There was an APWELL borewell, with 6 families growing chilies, groundnut and sunflower. Rotation: 1 acre per day.

APWELL Borewell 2: This had 2 acres of paddy. It was allowed as only one farmer would cultivate paddy this season (a drought). Other members had sunflower and groundnut so there was no problem with water.

APWELL Borewell 3: There were 4 people – the outlet had started in 2001, on quite steep slopes. They were all planting mango, as it would use less water, but it was intercropped – one area in sunflower and another with groundnut. The group did discuss crops with each other.

Well 4: KR Reddy well – There were four farmers, 20 acres. Three together had 11.5 acres. However one previous Backward Class member with 7 acres had now drilled his own well.

Other villages in the transect

UP : UP village lay in a basin underlain by limestones. It used to be famous even at district level for its number of dug wells. There was also a spring which villages recalled irrigated up to 300 acres of paddy. In the 1960s – before energisation – there were only some 10 dug wells operated by bullocks. The first diesel was used 1960-67 then electricity from 1967. In the period 1967-1988 180 dugwells developed, tapping water up to 24 feet – irrigating up to 88 acres of chilies, groundnuts and onions. The villages dug all these wells themselves. The spring dried up first, with the impact of the dug wells, and was dry by 1988 when the first borewells were drilled. The first borewells came from APSIDC in 1988: four were eventually developed (three under ‘normal’ programmes and one under special programmes). Private borewells then began to proliferate, and some thirty farmers tried for in-well bores in their dugwells. By 1995 there were 200 borewells, and a further 100 had been drilled since then, making 300 in total in an area of 1200 acres. By 2002, 50% of these were seasonal, and

only valuable for kharif crops. (They were dry by the end of January so useless for late kharif or rabi crops). The earlier borewells were drilled to 80 feet, the later ones to 200-250 feet. Villagers recognised which strata give water and that there was no yield found below 200 feet. They estimated that 200 acres were irrigated using leased water – the cost was 20% of the crop (water sharecropping), and leasing occurred in both seasons. It was happening more than five years ago. Recently SPYReddy wells had also come into this village. Some 70 had been drilled, of which 30 were ‘successful’. Some farmers had transferred their connection from an older seasonal well. As the wells were only drilled in March 2002 farmers did not know how they might evolve.

The villages reckoned they were benefiting in their water supply as they were lower than surrounding areas and are a natural collection point. The configuration of water development and water problems had left a very particular spatial configuration of groundwater availability. There remained a zone without borewells, with a ‘high potential zone’ in the south. The zone of seasonal wells was clustered strongly in the southwest, some of this close by UY village lands. Farmers admitted that pumping here might cause problems to both villages. On the one hand they said that they wanted to stop borewell development. On the other hand, they had benefited as a DPAP watershed from checkdams and trenches over the neighbouring hills, and were saying maybe they could irrigate another 200 acres with the water conserved!

UY: UY was a ‘problem’ village for water supply prior to the arrival of borewells, when the first APSIDC well arrived in 1985. Before that there were no dug wells for agriculture. There were no dug wells because of their cost to dig, the depth necessary, and the poverty in the village. There were 3 wells for drinking water, dug to about 60ft: but they dried up in summer when they had to go to KG for water. They had no local spring, although there was one at a temple in another mandal some 2km away. They

had a small seasonal tank for their animals (still there). Eventually APSIDC drilled 8 wells, seven under its normal programme, and one under its small farmer programme. Villages said there was now only one group well (with three members cultivating 6 acres), and the rest were operated individually. Actually only two were working now, including the group well. By 1990, 100 borewells were drilled under private development, and another 100 developed by 2002. Of these, APWELL brought 12 borewells, (these also serve 8-12 acres), giving some 200 wells in total. They only cropped in two seasons. However, 50 borewells were now seasonal in the western area, operating only until December. The village area was some 3600 acres, of which 600 are currently irrigated (16.6%): 1200 acres were irrigated up to 2001 (33%), but only 25% of this was irrigated in rabi 2002 because of the drought. Private borewells had been drilled to 150-250 ft, and some fifteen borewells had 7.5 horsepower engines.

Most APWELL borewells had a water sharing agreement, irrigating 2 days per acre, as initially they all had water sharing problems (people wanting to have water on the same day). All costs were divided on the basis of area irrigated. There was a BUA that met monthly, but did not yet have MACCS status enabling to organize other services.

KG: KG was a village of some 2000 acres, 25% (500) acres of which were irrigated. Set in hilly terrain, in 2002 it had borewells from all the programmes of intervention. It had 13 open wells, but only two were still being pumped. It had 4 APSIDC borewells, 15 APWELL borewells, 14 SPYReddy wells, and 34 private borewells drilled to 200 feet, all clustered closely toward a river that winds round the village, where check dams had also been built to try and improve water supply. Some zones of the village remained without wells.

Villages knew that one large open well was very old, and once served the whole village (and UY and BK) for drinking water some 60 years earlier. It also used to

irrigate 3 acres, but had not been pumped for 3 years – this was the effect of the borewells. There was now a borewell for drinking water. Another old open well, from 40-50 years old, used to have 5 feet of water in it and irrigated up to 25 acres. In 2002 it irrigated only 2 acres in the fields of one person, supplying water until the end of December (characteristic of open wells in shale there). These wells filled overnight and could irrigate 2 acres. Open wells were also being dug until quite recently – there were wells only 10 years old: one previously served 10 acres but was now abandoned. The farmer had no replacement bore – he tried and failed, and now there was an APWELL bore with four families downstream that would interfere with his well if he drilled one. However there was at least one dug well that had come back to life after an artificial recharge structure was placed by it. It dried up 7 years ago (it was dug 12 years ago).

The first borewell was a private one, some 18 years ago. Then followed the four APSIDC wells. One APSIDC well originally had 3-4 people from the same family, originally 20 acres. Now it was only 1 person and 10 acres. Another was still a group well with four people but the rest were individual. Only two people with dugwells got APWELL borewells. The SPYReddy group wells had 3-5 members, with different classes and castes. The BUA for APWELL borewells started three years ago and ran extremely efficiently, and wanted to become a MACS to offer other services. The BUA had to deal with water sharing problems at the initial stage, especially the problem of 2-3 people wanting to irrigate at the same time. They said that a rotation of 1 day per acres is all they need.

In 2002, farmers had multiple concerns over water levels, power supplies and costs, and asked for more technical guidance, as many said they still could not read literature given to them. The BUA secretary thought there was enough water and they needed to mobilise more, it was the problem of luck to find it. There were different opinions of water level variations across the year – some said only 30cm – others 3-4 metres – but

all agreed that the decline started at the end of December, and from April onwards several borewells were almost dry. Under their groundwater drought regime, they only irrigated two crops a year – to give the soil a break as well as because of worry about risks. They were thinking to move more into horticulture in the future, having seen 100a of communal lands put under dryland mangoes in a CAPART project locally. Thus here, changes in crops seemed the response to growing groundwater drought and scarcity, rather than adopting additional water storage or water saving technologies.

The experiences recorded from these villages at higher elevations in this transect showed again that it was locations that once had the best groundwater supply that had the biggest negative impact from borewells, with dugwells drying up and many borewells become seasonal, as in LD and UP village. Villagers had interacted with and used all the various borewell intervention programmes, and many of the borewells had survived. However, only the APWELL and SPYReddy wells seemed to have kept to their criteria of either serving only small farmers – or serving all farmers that can group to meet the minimum area criteria for borewell assistance. Dug wells had kept functioning only in KG in the upper hill zone, although at a much lower level than before, partly due to the impact of watershed conservation and artificial recharge through ponds and checkdams. Not only had estimates of groundwater potential given no guidance in these villages – there was further no real understanding or analysis of the wider regional dynamic of groundwater behaviour.

Villagers had built their own knowledge about water bearing strata, and the behaviour of their borewell water supply across the year. They had norms of what to expect and do in an average year – usually two seasons only – and in a drought year where they reduced area and only considered one crop season. Villagers were also investigating horticulture as a more reliable option in an increasingly uncertain water and power environment. No villagers had adopted any additional water saving or

storage technology. These finding echoes those of Chadrakanth and Arun (1997) that farmers were only rarely moving into new technology to irrigate with, unless economic scarcity is really severe.

5.8 CONCLUSIONS

By 2002, there was a new understanding about the scarcity of the Drought Prone Areas of Maharashtra and Andhra Pradesh - that a physical water scarcity with increasing problems of insecurity in water access was emerging because of poorly controlled water development. There was greater understanding of drought linkages – in how rainfall drought manifested itself almost immediately in hydrological drought, giving stress on groundwater and surface irrigation, and drinking water sources. However, while a number of NGOs experimented with new programmes, and some bilateral assistance programmes tried to introduce new knowledge frameworks like Water Audits and PHM, many public agencies hardly changed their methods. As definitions of droughtprone areas remained unchanged, but the technologies for droughtproofing like groundwater development proved less reliable, drought relief became the most prominent form of consistent public action (Mathur and Jayal, 1993). While some public agencies made their information more user friendly – through use of different media like television and internet – few were able to change their actual technical practices much. The changes that materialised were also shaped heavily by external or hierarchical relations of approval.

The nature of agency institutionalisation in a failed developmental state seemed to make change difficult. Mitigating against internal change in agencies were some of the problems noted in Chapter 4 – shortages of funding and personnel, corruption, lack of continuity in supportive research programmes and the politics of institutional survival.

Scientific and technical norms and methods became part of the identity of an agency, rather than any new vision of resource and technology management. The technologies transferred did not need much science for their dissemination. However, the sciences of agrometeorology and geohydrology also made little effort either to study interconnection across the water cycle, nor to develop criteria that could show the particular vulnerabilities of different water cycle elements under drought. Debates highlighting physical scarcity and competition for water came to transcend those about the nature of drought and water cycle behaviour. This was partly because these explained more the experiences of people on the ground, but also because the science portraying drought manifestations and their materialisation in society had remained so weak and abstract. Droughtproofing no longer needed dissemination of new technologies – it needed new management tools and new initiatives to promote equitable water access that could emerge from an understanding linking drought dynamics with structural water scarcities emergent from agency weaknesses. There had been new models and platforms within NGOs, and special bilateral programmes, which tried to bring the concepts and analytical routines for monitoring drought and scarcity together. Whether these can be made more regular parts of public agency and civil society in India in the DPA is a question for the future.

INTERMEZZO 11

This intermezzo acts as a break and a reminder, to set the scene again for studies from two very different drought contexts, very different state and agency contexts, and very different research contexts. The remaining cases now emphasise a much greater concern for participatory processes, and report on the struggle to build these into project processes (the Yemen case study) and in representation in water administration (the Zimbabwe case study). They also represent a very different level of cognition of my own work, and relate with the shadow ‘political economy’ question outlined in Chapter 1.

Both cases look at forms of hydrological drought – groundwater drought and surface water drought - and at very different hydrological contexts to the previous four chapters – at springs and cistern supply in Yemen and at river flow in Zimbabwe. Both studies also show stronger cognition of the need to combine hydrological units of river basins and watersheds with administrative and political representation. The two locations also have rather different overall drought contexts. Both suffer from marked seasonal drought, but very different patterns of uncertainty and vulnerability compared to the regions documented in India. Yemen, with its rainfall falling under 500 mm in some areas is drier and more ‘droughtprone’ than India – although it had no special agencies or programmes to combat this, and many development interventions were directed at improvements in water supply for health rather than agriculture. Alongside a long seasonal drought, the Raymah region of Yemen also had low overall annual rainfall that had created endemic levels of water scarcity, that local indigenous technologies of springboxes and cisterns and water rights were historically adapted to. Zimbabwe, on the other hand, was less ‘droughtprone’, with a climate and physiography that generated runoff whose capture and access became of core concern. Zimbabwe also

had no special agencies or programmes around drought, although social exclusion and underdevelopment had also given famine concerns early in its history. Rather, the Rhodesian/Zimbabwean state put water resources under Ministerial brief in a bureaucracy peopled by a scientific elite from relatively early in its history. The Manicaland region of Zimbabwe had higher rainfall, but scarcity problems emerged in the poor soils and runoff regions made into tribal trust lands.

Neither of these countries had the historical and geographical scale of famine to shape early public action that occurred in India: nevertheless access to water was also a fundamental control of economic opportunity which was factored into social and political relations of the countries and institutions for water management. Neither country, however, had either the traditions of planning documented in India, nor the democratic legitimacy of central and state government. The following two case studies rather offer examples of planning and cognition emerging respectively under highly local water management in Yemen, and highly coercive central governments in Rhodesia/Zimbabwe using scientific elites to first serve its commercial farming regions rather than poorer quality lands set aside for black smallholder farmers. Rhodesia under its colonial government could pursue coercive and racist strategies of land and water allocation, within which science and technology also operated alongside legal apparatus while also active in wider scientific networks regionally and internationally. Zimbabwe, perhaps as a result of this, had a good emergent hydrometric network for the study of rainfall and river runoff by the 1970s - although these networks were highly skewed in their density in relation to commercial areas and tribal trust lands. Alone among the case studies, it pursued a systematic development of its water legislation, that slowly but surely brought most water sources under monitoring and analysis - but under very particular cognitive and technical norms. Yemen on the other hand had almost no history of any state influence in the analysis and development of

local water resources. Its local knowledge and cognition was hardly even expressed in scientific terms – rather it was shown in certain critical dimensions of water rights. Both these case studies, however, show what problems and opportunities emerge when traditional political power collapses, and new opportunities for allocation and redress of historic injustice in water rights occur. In both cases, as in India, technologies become a major tool in social and hydrological control, but also the point at which change in water availability can be addressed – but with uncertain impacts on water rights unless these are investigated first.

These case studies show again the usefulness of the concept of ‘technology as legislation’ – as a tool for understanding why people favour certain technological systems over others, and as a value around which ideas, interests and institutions are marshaled, diffused and restricted. The Indian studies have shown the significance of local elites in agencies in shaping technology choices, and in institutionalising certain cognitive norms. In the following case studies, we see how local government and informal civil society had this power in Yemen, defending cisterns and springs and associated rights against new technical ideas. In Rhodesia and Zimbabwe, however, powerful central techno-scientific agencies held stronger controls over analysis almost universally directed to studying options for dam creation. Water rights were used as a means of control in water scarce conditions, rather than pursuit of new technology or a trust in the market that seems emerging in India. However, one weakness common to all case studies is the collapsing ability to allocate water in water scarce contexts without strong local legitimacy in water governance, and rules in use of technology. Technology choices by government can show meanings and ideas – but it is local control of water access that shows where real power lies. Ironically, in all these case studies, the issues of local power has become more obvious as our scientific and technological capacity to study the water cycle has increased, but the determination to

administer equitable governance of water has not been backed by relevant judicial and technological powers of control.

CHAPTER 6

GROUNDWATER SCARCITY IN THE YEMEN REPUBLIC

"Raymah people are whimsical people: we work with them as if we are walking on eggs".
Director, ironmonger/hardware supplier, Hodeidah

Tacitly understood traditions of technological knowledge co-evolve with technological paradigms but evolve themselves outside the realm of science....Scientific patterns cannot be perfectly extrapolated for complex, non-trivial technologies andtechnical change is dependent on learnt conceptions of similarity that cannot be reduced to information processing. Nightingale, 1998.

6.1 INTRODUCTION

In the years 1985-1987 I worked as a water specialist in a Water Unit funded by Oxfam supporting drinking water development in the Raymah sub-governorate (in the Sana'a governorate), in what was then the Yemen Arab Republic¹ (YR). This mountainous area with low and often uncertain rainfall in the range 400-650mm, nevertheless had an agricultural system and stable water management technologies, at that time under a rapidly changing tribal system of local management. Water supplies were very limited, and critical sources were small spring seepages or spring-fed streams, or cisterns that stored runoff and seepage water.

These unique traditional water storage systems, uncertain water supplies and rapidly changing local-centre politics, created a very different kind of droughtprone area, development arena and cognitive space, with many more locally-based institutionalised actors. Available water was almost fully allocated, and access was managed under customary law. This was designed to mediate access to scarce water resources via technologies that supplied finite but largely known quantities of water despite seasonal fluctuations. These local adaptations and customary laws with embedded tacit knowledge about technologies represented cognitive norms quite distinct from those of

¹ The Yemen Arab Republic was united with the People's Democratic Republic of Yemen in May 1990 to form the Yemen Republic.

western science outlined in previous chapters. Scarcity was recognised as a condition to adapt to, rather than a consciousness of risk and vulnerability under drought. This case study thus gives a very different insight into the relations of science, technology and agency – of dynamics where technological awareness becomes far more critical than scientific knowledge. It also gives insight into the dynamics of agency in the processes to resolve struggle and disputes to access water, and the synthesis of differential knowledge and visions about possible change. As well as describing these norms and practices, the chapter ends with a summary of a water conflict that encapsulated these differences, with a view to learning more about frameworks for collective action that can openly allow for disputes. The chapter draws on other published papers (Vincent, 1991, 1990, 1986).

Section 6.2 summarises key features of the environment of Raymah, and political changes that set the stage for the water struggles documented here. This is followed by sections giving more details on Islamic water law, the reality of local water management and planning and wider effect of new technology on water mobilisation, none of which had been described to the project before this work began. Section 6.5 documents the successes and failures in work with a local plan for water improvements in domestic water supply. This section also summarises details of a summary of a conflict over renovation of a spring supplying irrigation water that led to the end of the Water project in Raymah. Section 6.6 gives conclusions to this case study. Contrary to several framing discourses, it was neither type of sources nor artefacts that precipitated water disputes, but rather a particular configuration of interests that allowed for opportunism in claiming access to water. The most difficult areas to develop for communal drinking water sources were tribal 'boundary' areas, and 'communal' and 'unoccupied' lands. These were often stretches of mountain or unsettled wadis, which carried groundwater, but where jurisdiction and rights were uncertain. Tribal groups

were concerned to preserve their traditional rights to water in their territories, such that they would dispute new proposals for use, or any change in status to pragmatic access they may have granted to other groups.

This case study shows a situation where it is technology that reshapes science, and that western science is largely unable to characterise or parametise such complex artefacts. Also that tacit knowledge does not get exposed easily – local surveys and discussions did show local indigenous knowledge (science) on resources, but not even longer interviews and discussions revealed all the intricate possibilities for its transformation. Sometimes these only emerged as physical intervention in a water system began. I realised that, to become a competent scientist and practitioner, I had to understand and interact in politics.

6.1.1 The project structure

The Oxfam Water Unit was based in Al Jabin village and uzla: the Unit staff consisted of myself and a Yemeni counterpart, and groups of workers hired in as necessary for construction. I lived in the village, and these counterparts and workers were local people. The empirical data for this study comes from almost three years of work that involved rapid rural appraisal of resources, more detailed field surveys, discussions as we stayed over night in villages during planning and construction, participatory design methods, documentation from council meetings and interviews with key actors including state officials, council representatives, PHC workers and water users. We did surveys of water use and water sources in 11 villages which were potential system development sites. However, only 3 of these sites were approved by all partners as technically, politically and financially feasible, and only 2 water projects were

completed (an improved village water point in Howrah and a piped gravity system in Gotto), before attempts to construct a third in Matlas village paralysed the programme.

By virtue of its distance and inaccessibility, Raymah sub-governorate had received only limited attention from central schemes in water supply. Raymah had, however, been a focus of OXFAM aid with a Primary Health Care (PHC) Programme for some time. Village water supplies were seen as a natural focus for extending the effects of the health programme and making health impacts more visible (Oxfam office notes, Sana'a, 1983; Merabet, 1984). Oxfam had another water project in Yemen, and I had visited both areas when part of a short evaluation mission in 1983. Through this local contact and through local project work elsewhere in the YR, OXFAM was aware of the responsibility of local councils in improving water supply, and the keen interest of villagers in improving their water supply. Thus a programme was developed with twin aims: technical assistance which could improve planning and implementation capacity within the local council, and water source improvements to strengthen PHC work.

This aid initiative combined financial and technical assistance from OXFAM with financial and administrative assistance from local councils, and financial and labour inputs from villagers, with central administrative assistance from the Confederation of Local Councils for Cooperative Development (CLCCD). The approach was to design water projects for villages with a PHC centre, which also figured in the local council budget for water projects. The focus on villages with health centres concentrated the work of the project, and enabled exclusion of general demands for assistance from other villages. (Oxfam office notes and minutes, Sana'a and Oxford, 1983). The PHC worker of the area could also provide additional information on water sources and liaison for project development, although there was no reason to suppose that such advice would be impartial. Disputes and delays in assisting PHC villages led us to try to assist other villages in the local council budget. We also became involved in villages

with PHC centres, where water improvements had not been costed into local council budgets, because representatives had considered supplies to be adequate. It was hoped that this project could provide a model for work with local councils, under the guidance of central Ministries, since most of the funds available within the country for rural water supply lay with the local councils in the 1980s.

6.1.2 Tacit knowledge and framing objects in the DPA of YR

The expectations and approaches of Oxfam and myself were already influenced by several debates discourses and learned experiences of the donor community, which later proved rather unhelpful. These included:

- 1) a conviction to work with water as a health issue rather than a resource or justice issue, as basic needs were one of the core reasons to justify work in Yemen. We had to relearn the possibilities to survive on very small water supplied in our designs, and even ignore conventional standards of supply² if we were to reach any point of contact with villagers. In fact our entry point also had to be a resource access problem, absolutely involved with concerns of local rights and justice, if we were to convince villagers to work with us. We had access to several good survey reports on domestic water use (Ansell, 1981; Tutwiler et al. 1980; Yacoob, 1983). However, I was given no summary of customary law (nor were these available for any technical workers), and largely compiled my own record which is summarised in section 6.3;

² The convention was that a standpipe supply should provide at least 40 litres per capita per day, but this often had to be relaxed below this where water was limited. (Laredo, 1986). Health benefits came from quality improvement (especially reduction of faecal contamination and reduction of bilharzia risks) and reduced collection problems, and some increments in amount of water used. Typically, a household used around 100-120 litres per day (5-6 twenty-litre jerry cans) or 20-25 litres/per day/per capita. This per capita consumption could be about the same or less as that also organised for livestock. (Tutwiler et al, 1980; observations in Al Jabin district, 1985).

- 2) donor wisdom that borewells were the preferred source (although not without problems), and that springs, cisterns and water tanker supplies were all unreliable sources for water improvements because of possible conflicts, health risks, and the high operating costs of tankers which also faced 'turnover problems' (UNDP-UNCDF Project Evaluations, 1980-1983) We had to realise that actually no source was impossible to redevelop – it was the social space of the technology, and not the artefact itself, that was in fact the issue. These issues are covered more in sections 6.4 and 6.5;
- 3) a lack of differentiation in the dimensions of scarcity behind limited water supplies. Many tended to highlight the *depletion of resources* (as in Chapter 5), where farmers and communities were largely characterised by *helplessness*, because there were no rules to encompass the technology, and the new technology itself required no social interaction for its development and installation. However, the conflicts in Raymah were more often over *misappropriation of water*, and institutions had to encompass adjudication, often after *physical violence and destruction*. Little was written by 1984 about the different roles and relations of agencies for these different conflict fields in water;
- 4) Institutional arrangements proposed for water projects were often rather normative in the formation of associations. However, these failed to differentiate whether water management problems came from unclear institutional arrangements for use (including property rights and access to water) or absence of an authority system to give meaning to these arrangements (Bromley and Cernea, 1989). We started thinking that the 'problem' was institutional arrangements within systems, but the real issue was authority. In fact it was this absence of authority, and the confusion and opportunism that emerged as authority was shifting from local to state-appointed actors that fuelled possibilities for conflict in this project. Also, the

property³ arrangements – private, state, common property, open access – varied, so too did the authority system and rules called in to deal with them. Another of our early mistakes was to look to only one section of the local administration to answer all questions about water allocation, management and use;

- 5) Disputes were seen as a problem and a sign of trouble, that good participatory dialogue must try to prevent or diffuse. I learned that it was disputes between groups and not within groups that were a more critical issue, for which no PRA skills and few ‘platform’ studies could prepare you for the ways these moved in space. I had to recognise that I was working in a society where disputes were a normal form of social interaction, through which individuals and groups constantly tested their position and opportunities in a changing world. Working with disputes, even if it seemed like a constant degree of fire-fighting, was actually an important source of personal validation to others, and really the only viable source of information for the realities of water management. Rather, it was conflict and related violence that was the danger, in the way this could shatter people and their reputations, and could bring loss to individuals and communities (Parnell, 1988). Disputed claims on natural resources between groups could only be addressed further after one group had agreed and taken a public debate and decision. I have come to agree with Hunt (1990, p.145) that...” conflict arises when disagreement becomes a public issue”, which in Al Jabin came when disputes could no longer be dealt with within a community, such that a local group has to turn to a supra-community group to deal with ‘supra-community’ problems. Many impasses arise in water programmes because governments or donors rarely reflect on whether and

³ Bromley and Cernea (1989) defined property as a right to a benefit stream that is only as secure as the duty of others to respect the conditions that protect the stream

how to strengthen the supra-group or whether to strengthen the community so that it does not have to turn to supra-groups so often.

6.2 AGRO-ECOLOGY AND SOCIAL CHANGE IN RAYMAH

6.2.1 A mountain region in transformation

In 1983, the Sana'a governorate covered diverse but important areas of the Highlands (1000-3000 metres) and straddled an important political divide between the Zaidi tribes of the north and Shafites of the south. Raymah consisted of 5 districts. Al Jabin was the largest of these, covering an area of 600 square kilometres, with a population of around 80,000 people at the 1981 census. The average population density was then over 130 people per square kilometre - quite high for a dryland area. Actual settlements depended on water supply and local climate, and population densities were lowest in some of the foothill valleys. Each district was subdivided into *uzlas*. An *uzla* was the smallest administrative unit and its boundaries usually reflected older territorial rights of families in the area, drawn in relation to geographical features like mountain valleys (wadis) and rock outcrops.

Some limited rainfall records existed for Al Jabin, but not in detail for the whole of Raymah. I estimated that the annual rainfall was around 650 mm on the western slopes, falling to around 400mm or less in the east. Rainfall was highly seasonal, concentrated mainly in the months of March-May. There was also no data on rainfall reliability and drought frequency, but the cropping system was regarded as a stable one, reproducible in most years. Oral reports added that the area was subject to lower and more variable rainfall since the late 1960's, with the worst effects in the eastern parts of the mountains.

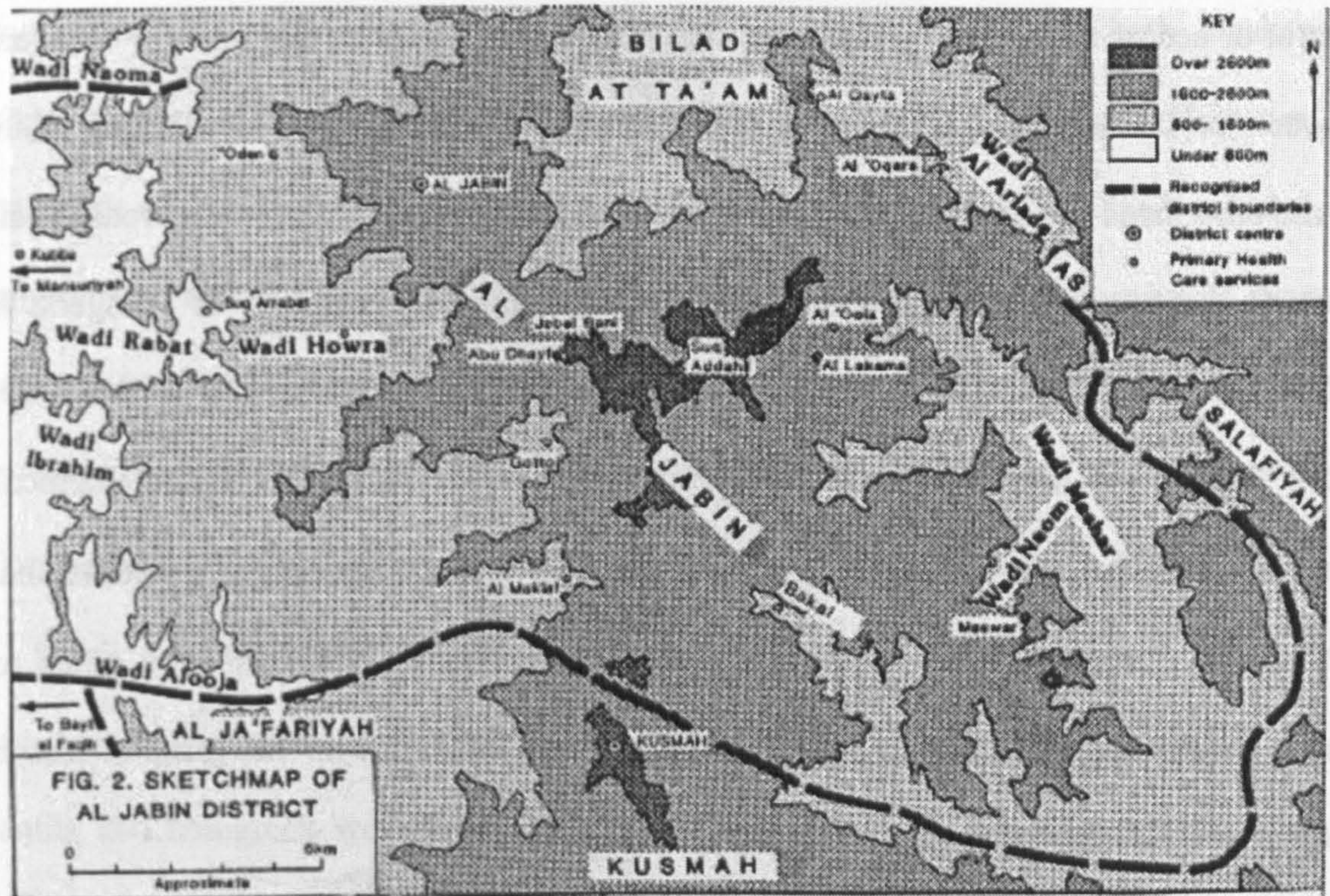


Fig 6.1 Sketchmap of Al Jabin district

Agriculture in these mountains was predominantly rainfed: irrigation water was at a premium. Most available sources of water were used both for domestic water supply and irrigation. The increased demand implicit in improving domestic water supply meant fitting a further demand for water into an intensively used water system, and the technology involved could raise many challenges in the field of existing law.

On a mountain, the 'losses' of one area supplied water for other users down mountain: villagers faced complex questions on whether to opt for improvement of existing sources or whether to exploit 'new' sources of water, any of which might cause consequences to topographical neighbours. The advent of technology that allowed the incorporation and movement of 'unutilised' water at a point in space, like pumps and pipes, could create a spatial reallocation problem outside the scope of existing customary legal controls. Thus villagers could justifiably fear the impact of projects on their water rights, and in reverse, new technologies and pressures might be exploited by local interests to gain greater

control or access to available water supplies. There was a serious dilemma for villagers between, on the one hand, wanting an improvement and risking new technologies, while on the other hand judging the ability of local legal forums and foreigners to protect their interests. Learning to discuss and understand this strategic cognition of villagers, in addition to just technical details of resources availability, was the hardest shift for me, and I think is still rarely appreciated by many technicians helping with development projects - even though misjudgements can have disastrous consequences for communal entitlements. This issue was particularly crucial when local villagers were asked to accept a technology that they cannot visualise, so that they have no full grasp of how it could affect their environment.

It was thus important in this work to understand the difference between the physical location of water and its social appropriation. Regardless of whether we could physically find new resources or reorganise existing ones, all water was theoretically allocated over a social landscape that mixed private and communal land, and communal and private rights to use water: these controls were still very strong. As we discovered, just because a village had a right to use a water source, or identified a previously under-utilised source, this did not mean that it had a right to develop it.

Local interests in the mountains of Raymah were complex. At that time, in many respects there was still a tribal organisation operating through the extended family, with many communal customary entitlements in control of water and access to land for fuel wood and fodder. This customary law was still largely applied through representatives selected for traditional management roles. Alongside this, however, operated extensive private interests in land and water. Landholdings were frequently large, with considerable sharecropping of production from both rainfed and irrigated land. This tribal system had been under pressure in parts of Raymah for many years. Early influences included the impact of the Turkish occupation on the western slopes of the

mountain, and more recently the effects of out-migration, which both weakened sharecropping arrangements and the scope of agreements over water use. However, a hallmark of the inhabitants of the area was an intense loyalty to their land, which led migrants to return and attempt to invest their savings in the area despite its scarce resources. Such attachments to the land perpetuated an involvement with customary rules on resource use, which were tribal in origin, even if allegiances and ties between families and representatives were under stress (village level discussions, 1985).

Land was extensively terraced on all but the steepest slopes. In Al Jabin, sorghum/bean intercropping was the main rainfed land use, but other pulses such as lentils and fenugreek were produced, while grass collected from fallow terraces was important for livestock and draught animals. The main crop irrigated on the mountain was coffee, especially on the western slopes, with some production of vegetables and qat elsewhere, and some irrigated sorghum in wadi areas. Where coffee was traditionally cultivated in Al Jabin, it continued despite competition from other irrigated crops. This was partly because of the isolated nature of many of the mountain slopes, and partly because coffee had low water requirements, and low labour requirements in husbandry and marketing, relative to other crops, while still having a good market value (Field observations, 1985-1987).

6.2.2 First assessments of the water cycle

This terracing and cultivation pattern had considerable influence on the nature and volume of the available groundwater. In Raymah, the geology was largely metamorphic and volcanic, with groundwater only available in fissures, faults and bedding planes, so that seepage under the terraces was an important part of groundwater resources. In some valleys in Raymah there was sufficient infill of unconsolidated materials to

conduct water, but even in these wadis subsurface flow appeared to follow sub-surface drainage lines, so that its development could be unpredictable. These groundwater resources supported seepage points, springs and a number of perennial streams, although their point of emission and discharge fluctuated seasonally.

Classifying the hydrological nature of groundwater sources was very difficult, and I found it much easier to identify types of water sources by the technology by which they can be mobilised, which also reflected rights to ownership. Price (1985) defined seepage as the diffuse flow from an aquifer at the surface, and a spring as localised flow such as would result along a fault or fissure. In Raymah, they could be difficult to distinguish. I use the term seepage point to mean very small discharges under 0.001 l/s (mainly found across the hills and terraces), and springs for larger flows. Most seepage points and springs were small, and water was ponded in small springboxes or cisterns before it could be used. Larger springs were either left to flow as streams, or were piped to irrigated terraces depending on the spring and its owner. I use the term 'groundwater streams' to distinguish the springs which support larger, perennial flows or water (over 10 l/s) and which were left to flow naturally.

There were seasonal floods in some sites, but flows were flashy, and there was no spate irrigation, such as is found in lowland valleys (see Makin, 1977 and Varisco, 1983). We did, however, come across isolated examples of flood offakes for terrace inundation, and oral references to defunct water harvesting systems for irrigation.

Settlement was in a mixture of villages, hamlets and isolated homesteads. In Al Jabin, the typical size of a village was 200 people, but ranged from 50 to 1500. This diffuse settlement pattern was one of the first challenges to an appropriate rural water development plan. Across these mountains were a variety of water sources used for irrigation and water supply. Some rainwater was harvested in cisterns for general domestic use (washing, watering animals etc), but most drinking and irrigation water

was mobilised from springs or streams supported by groundwater flow (see also section 6.5). At this time, hand-dug wells existed to tap the unconsolidated materials found in mountain valleys (*wadis*) and the foothills. Borewells were starting to proliferate in the mountains, because of construction technologies available, and because they offered the opportunity of private development of water supplies (surveys Wadi Ibrahim and Meswar, 1985 and 1986).

The main changes affecting these resources were:

- a) increased domestic pressure with population increase and greater consumption;
- b) the abandonment of more remote terraces to fallow through the effects of war and migration;
- c) increased markets for irrigated crops;
- d) drought, deforestation and road building combining to have unpredictable effects on groundwater flow;
- e) new technologies for mobilising water.

Thus not only was there increasing competition for water between uses, but also quite a lot of hydrological uncertainty, as both natural and economic changes affected the local hydrological cycle. While other economic opportunities remained limited, other social forces thus tended to increase the tenacity with which rights were held, and increase the search for opportunities to circumvent them. In such an environment, few interventions could be neutral, and negotiation became crucial. My three years here taught me how hard that was.

Where there were few opportunities to find new sources of water, the only other current option for local people to expand their domestic water use was reallocation, which tended to happen through opportunism rather than negotiation. For feasible interventions, we had to understand: (1) what 'new' (unutilised) resources we could bring into a location (2) what reallocation in uses could take place at a source or

spatially between sources, and (3) what reallocation could take place between users, either at one source or spatially between several sources. My own hydrological training had given no exposure to questions like this – yet failure to understand this was the most rapid way for a donor to become ‘used’ in the reallocation process. For all these questions, it became absolutely essential to understand not only the presence of water on communal versus private land, but also the private and communal interests of villagers using the particular water source. This was tacit knowledge that took time to understand and assimilate, and was only made clear from getting involved in the mobilisation of sources and construction of systems.

The option of massive water imports to some parts of the mountain was dreamt about by some local representatives, but had been avoided by government and aid donors who feared the implementation and operational costs, and political challenges, in serving a mountain with a diffuse settlement pattern and tribal loyalties.

I had no detailed information on the water balance of Al Jabin, and thus began work with my own conceptions of ‘losses’ and ‘surpluses’ of water that could be developed for water supply⁴. We had a feasibility period of three months that enabled us to obtain a feel for the type and scale of water sources present over a landscape for which we had limited maps giving physical contour information but no data on villages and water sources. Heinous though it might seem to some that we started work with so little information, our feeling was that going operational was to some degree essential to show commitment and gain more insights about the locality of water and its control. What caused most problems eventually was not so much limited data on water resources. The problem was limited understanding of these tacit ownership claims -

⁴This situation is not uncommon for water developments in the YR (or elsewhere in the developing world), because of government emphasis on funds being used for implementation rather than feasibility studies.

how villagers and local representatives controlled access to water, how villagers conceptualised their rights, and how new interventions challenged these rights.

Our starting conceptions were that there was some outflow from the montane hydrological system to the west and north into the Tihama groundwater system (see Fig 6.1). This outflow occurred though flash floods after heavy rainfall, poorly utilised groundwater streams and also evaporation losses in streams and irrigation channels. We recognised that the flood runoff gave soil recharge to the lowland production system, although often damaging to field crops and unpredictable in its location: so recommendations on source development and rainwater harvesting would have to take this into account. However, we felt that some options did still remain, in excavation of some new spring points, renovation of springboxes, lining of irrigation channels, and better allocation of flow in certain poorly utilised groundwater streams. (The Tihama groundwater resources in the zone neighbouring the mountain was also at that time relatively undeveloped for irrigation). There was also potential for borewell development in some foothill sites, which could compensate for any decline in water levels in shallow wells if multi-village projects could be developed, although yields were liable to be low. In this respect, the most vulnerable villages were at the head of the foothill zone in the relief range 800-1500 metres, because of all the water claims around them (village surveys, 1985-1987).

Almost from the outset, we realised that developments on the mountaintop and to the east were far more restricted in potential, although unfortunately these were also locations with highly enthusiastic and politically active PHC workers and officials. A few possibilities did present themselves for source renovation, without immediate downstream effects, but for some villages we saw no possibility of augmenting supplies without conflict, as improvement could only involve come from the transfer of water from another source to a village territorially contested by others. Also, as sources were

small and dispersed, this meant financing projects with high per capita costs and sometimes very low per capita consumption levels. These initially provided severe challenges to design procedures and decisions, as Oxfam itself and other central agencies had to convince themselves that interventions still brought benefits and were 'good' development. Several of our project designs would supply under 40 litres per capita a day, thus assuming that other sources might still need to be used (like cisterns) for drinking water supply to be sufficient for a whole village. All of our designs also worked with collective spring points, or standpipe systems, and never with house connections, mainly to keep consumption low – although in one case a village later adapted the system configuration to give more house connections.

6.2.3 Changing governance

The republican framework of government in the YR began in 1962, when a military revolt overthrew the religious autarky of the Imam and proclaimed a republic. This revolt was followed by a protracted civil war, which ended in 1969. A new Constitution came into force in 1970 (Caponera, 1973). Concerted development effort began in the YR with a Three year Plan 1973/4-1975/6. There had been three five year plans (FYP) by 1984, which had developed both central and local expenditure programmes. Constraints on central government funds meant, however, that finance for drinking water improvements were raised either from aid donors or from local sources.

The Constitution stipulated that Islam was the state religion, and Islamic law (Shari'ah) constituted the basis of all legislation. Nevertheless, much of the Highlands of the YAR was characterised by a tribal political organisation with its own customary law. While this often derived from Koranic guidelines, there were customs that predated Islam, which were recognised providing that they did not conflict with

Shari'ah rulings. The tribe itself could take responsibility for law and order separate from other courts, and this was particularly common in water conflicts.

Thus one of the key political issues had always been the coordination of local representatives with the central government. The derivations of forums and procedures inevitably reflected both tradition and new political ventures. Both of these could involve religion in an Islamic country. The Tihama and southern areas of YAR became Shafite in doctrine (a Sunni sect) in the early years of Islam. The population of the Highlands became Zaidis, (a Shiite sect), following Zaid, who was connected by marriage to the family of the Prophet Mohammed. In Raymah both groups were present, including sheikhly families claiming dynastic links to the Prophet Mohammed. The western slopes of Raymah also experienced Turkish administration in first part of this century. Al Jabin district was thus a particularly complex mixture of old and new families, powerful elites and poor villagers (including ex-slaves), and old republican and rehabilitated ex-royalist fighters. It proved a particularly difficult environment in which to assess the reality of tribal traditions in water management and the scope of new civil structures in encouraging water development.

Although the advent of the Republic did not change the scope of existing laws, it did change their administration. Traditionally, disputes had moved through a series of local representatives, depending on the scale or nature of the problem. Many local leaders had derived their wealth from fees for settling disputes which had moved beyond the scope of the traditional local representatives (see section 6.5). However, by 1985, many districts had a centrally appointed, legally trained district officer (*mudiir-al-nahiyya*), available as a judicial alternative, or who participated in adjudication alongside local leaders (he was also there to ensure security). This availability of 'central' justice meant a loss of power for some local leaders, and also represented new opportunities to present claims in water disputes. Although we did not understand this fully initially, it

was inevitable that pressures from economic and technical change, together with these legal changes, would bring a clash between these systems in adjudicating claims on key resources - like water.

Islam had also been used to shape and fund local administration at this time. Prior to the revolution there was no standard local administration, and the new central government needed a structure to link the provinces with the centre. They used the Islamic principle of welfare groups, originally called Local Development Associations (LDA's), but these were not an indigenous local structure. These associations grew from 29 in 1973 to 203 by the end of the first FYP. With the shortage of educated manpower in the rural areas, many of the posts on these councils had been occupied by influential landowners and religious representatives, especially early in the history of the LDA's. In Al Jabin, PHC workers were often related to local council representatives, or become representatives themselves, and were almost always part of families with substantial agricultural interests. There was no reason to expect them not to promote their local and personal interests within political support for improved water supplies.

These associations had their roots in Islamic principles of charity, particularly the 'zakat' donations required from all Moslems. Religious guidelines on zakat did restrict the access by central government. 'Zakat' is a portion of personal wealth to be set aside for the needy and the poor, and is recognised as the second most important activity of Islam after worship. Guidelines exist for all forms of wealth in agricultural production, merchandise and personal wealth. The use of zakat should be organised, and only be distributed individually if there is no local communal organisation. Other rulings include: that the zakat of every locality should be spent in that locality, and that it is not good to send zakat from one locality to another except in cases of calamity. Finally, a share of the zakat can be paid to those that collect it.

Until 1985, LDA's had considerable autonomy in the collection of local taxes (there was a local annual 'head tax' in addition to zakat), and their subsequent use. The most popular targets of funds had always been schools, health clinics, water projects and roads. The collection of taxes was overseen by the Confederation of Yemeni Development Associations, who returned 75% of funds collected, but who themselves had little budget or manpower for monitoring either the collection of zakat or the efficiency of expenditure. In 1985, the structure of local councils was revised. Local councils were renamed Local Councils for Cooperative Development (LCCD's), who coordinated representatives from the smallest administrative unit, the uzla, into a local district council, which were then linked to subgovernorate and governorate administrative councils. (These arrangements and councils no longer exist⁵.) Zakat taxes were collected by the Ministry of Finance, and were given back to the local councils as an agreed budget, not simply a fixed percentage. This budget was drawn up at the district level. By 1987, the Central Ministry had begun audits of LCCD and closed several for financial mismanagement. In the water project work, we found working with these budgets involved problematic issues of the exercise of power. Proposals reflected what representatives wanted to happen, for personal interest and apparent constituency support. Nevertheless, it was in these budgets that our reputations and options had to be developed, if there were to be any prospects for improving rural water supply. (Interviews with CLCCD and LCCD leaders, 1985-1986).

Thus in Al Jabin we had subtle but critical distinctions between institutional actors involved in (1) local traditional representation of customary law, (2) those concerned to promote new uses of water, and (3) those administering disputes. Failure to understand

⁵ In 2000, a new Local Authority Law was approved by Parliament, which mandated elected local councils, which also had a new range of decentralised financial and administrative powers for

them and to access the right people meant failure to promote an appropriate forum to gain information on the physical availability of water and the social space for debate. In the programme discussed here, tensions between old and new legal representatives, and elected representatives and villagers, all came to be reflected in struggles to obtain water projects. However, when I began work, I still looked to conventional elites – village sheikhs, PHC workers and teachers – for most information.

6.3 TRIBALISM, ISLAM AND CUSTOMARY LAW IN WATER MANAGEMENT

The existence of an extensive body of Islamic law for all aspects of society, and the central importance of water in many Islamic societies, has misled donors into thinking that there is a cooperative spirit in the development of water projects, and that there can be a forum in which management solutions are easily hammered out. This was far from the case in reality, for several reasons.

The first reason was the ongoing recognition of customary law in water management, which was actually very complex because of the practical day-to-day concessions that often underlay the ideal principles. Secondly, while the importance of 'brotherhood' and coexistence in a tribe meant that disputes would be settled within customary law where possible (Mahdi, 1986), this did not prevent disputes which were often opportunistic and irrational, and sometimes very bitter. Most disputes went to wider courts only in desperation because of cost, unless these new courts provided a specific opportunity to make a claim. Thirdly, religious guidelines could only be used for problems discussed in the Koran or subsequently derived bodies of law. New technologies, especially pumps, borewells and pipelines, provided huge challenges to

customary and religious law which many enterprising farmers had no qualms about making in the 1980s.

Another reason was the distinction between which aspects of water management were collective and what could be privately controlled. Even though the 'Law of Thirst' insisted that all individuals must be allowed to drink water, the nature of access could become very different between water sources and as competition for water developed. In Al Jabin, no one was ever refused a drink of water, but the controllers of a water source could and did refuse the right of individuals to fill containers, or charged them for this activity. The opportunities for drinking water development offered by the Law of Thirst were also made more complex by an additional guideline that water should never be wasted, and that any surplus water should be always made available for irrigation. These 'tacit' guidelines caused some specific design attributes of water points, although at first I saw these as just poor construction.

One key to understanding these guidelines on access and appropriation was the rule that water cannot be owned or charged for unless it was stored and measured. Thus in terms of water as property, water resources management was collective: it was only after that it was mobilised and conveyed that it could become private property. Mahdi (1986) noted that water rights may be seen as private property, in that they could be inherited, sold or rented/sharecropped, but were not actually thus defined. For most situations, there was a tension between a natural tendency for individuals to attempt to control a water source in its entirety, and the preservation of access by a group.

Water flowing in small natural streams, irrigation canals, and from springs and wells developed jointly, was subject to joint ownership, with upstream users having priority over downstream users. However, water contained in receptacles or tanks, or wells and springs developed by an individual on their own land, was subject to private appropriation. Some Islamic sects recognised the principle of 'harim', whereby no water

project could be constructed within a specified distance of another project. In the YAR this distance was supposed to be 500m for well developments, but there was no evidence of this ruling operating in Al Jabin. Finally, anyone who developed a water source on 'unoccupied' land could lay claim to that water (Caponera, 1973). I show in section 6.5 that this last guideline was an important cause of disputes in the mountains of Raymah.

There were then relatively few sources of information in Arabic or English on customary law for water in the YR (Makin, 1977; Varisco, 1982, 1983). The work available, however, stressed a division between the organisation of irrigation water from flash floods or intermittent streams, and permanent flow supported from groundwater. Varisco (1983) distinguished these as 'sayl' and 'ghayl' respectively. Varisco (1982) also cited the Islamic jurist Al-Mawardi (1960) as distinguishing three types of spring:

- 1) natural flow out of the ground, which was free for all to use;
- 2) springs opened up on private land;
- 3) springs opened up on unowned land, the effort of which conferred private ownership but with certain communal obligations.

Thus 'streams' in particular had a variety of forms of organisation of water rights depending on their hydrological origins. In Al Jabin, all streams were supported by groundwater flow. Since these streams might result from any one of the three kinds of 'spring' flow discussed by Al-Mawardi, we had some variety in the organisation of water rights for their use. These rights were complicated further by the issue of whether there was land by the stream for cultivation, or whether water had to be conveyed.

Varisco (1982) went on to discuss the importance of understanding exactly what a 'share' or 'right' to water was, especially the need to distinguish between rights of access and the physical appropriation of amounts of water. In Al Jabin, conflict or uncertainty

did arise over drinking water projects, because installation of piped water to a village previously having only rights of access to a water point was seen as a form of physical appropriation (see section 6.5).

Both Mahdi (1986) and Varisco (1983) discussed the way tribal groups developed a management strategy in relation to available technology, judicial rules and norms of social conduct, and not only to water quantity or source. Mahdi (1986) (like Bromley and Cernea, 1989) noted how there was a dual challenge in water management: that posed by the environment, which the group overcomes by using its technical knowledge, and that posed from other groups who compete for water. Given the complexity and flux of legal provision at the local level, it became critical to differentiate what could be determined within the tribal water management system, and what could be directed by the state, and what was not resolvable by either in 1985. This legal control affected not only the technical scope of what we could undertake, but also the kinds of risks that villagers and representatives would take in claiming and intensifying use of water sources. Some aid donors had moved to the idea that it was certain types of water sources which are undevelopable, especially springs and cisterns. I contend here it is rather the way a particular source offers scope for political opportunism which determined the likelihood of water disputes.

New technologies and new interventions are new opportunities for personal power: in this work I found they were not only being used to circumvent rules in order to obtain individual control of water. They were also being used (as were the donors with them) to renegotiate or stake a claim over resources. Also, disputes were raised and taken to new forums as a way of exposing previous legal settlements over which there was still tension. Sometimes these disputes were used to settle personal scores.

Mahdi (1986) pointed out the subtleties of tribal water use that can confuse any outsider trying to understand, let alone rationalise, water use, in his study of a Berber

community in the High Atlas of Morocco. He made four observations on this community which were relevant to Al Jabin district. The first point is that even though rules might appear precise and complex, they were actually only theoretical guides, and were often corrected and adapted to the difficulties of the moment. Mahdi noted that the same Berber who enthusiastically described the delicate communal water sharing system that controlled his life would also explain how this system could be circumvented. Peaceful coexistence was important, and rigid adherence to the rules signified a crisis in the group.

The second point was consequent to the first. Rules were periodically ignored, so that while the system served as a foundation, it was supplemented by improvisation. Such adjustments were not part of traditional law, but were derived from local customs and relations, so that it could be difficult to understand the real local daily organisation. The complications were such that tribesmen preferred to discuss their system in the ideal terms of water rights rather than the actual utilisation. Thus oral history on the actual permutations of water access, and why it was permitted, was a vital key in the operation of the system. We found this also in Al Jabin.

Mahdi then discusses how this knowledge was held by specialists who distributed the water, or notables in the village who took responsibility for water. This point was very important, as it emphasises the role of knowledge in the community as well as allocative roles. By virtue of being monopolised by a few, this knowledge could be manipulated if required. The status of those who used the water, the oral historians, those who allocated water and those who legislated, and the balance of power between them, were factors that determined how water rights were interpreted and enforced, but this balance was always changing. It was this evolving balance which lay at the root of many disputes in Al Jabin.

The final point from Mahdi's work concerned the way physical and technical constraints led to the communal use of water, which in turn prevented other groups from using it. He described the existence of groups within the tribe, endowed with specific territory. Each group consisted of several villages, each of which was a conglomeration of lineages from several extended families. Members of the group shared a strong identity in three ways - of territory, of social origins and of mutual defence. This group appropriated the resources of its territory, including jurisdiction over water, with rights to defend against the ambitions of neighbours and protect its members. However, rights of use did change with conquest and land ownership. Mahdi made the important distinction of two models of communal ownership - property of the group and property of the village. Thus rights could actually change their form between smaller and larger social groups, with rights distinguished between smaller and larger social groups, and between groups, villages, lineages and extended families. Allegiances altered depending on the location of the threat.

Such patterns of allegiances also appeared to exist in Al Jabin, and possibly explained why certain projects could be developed without difficulties, whereas elsewhere projects proved impossible. However, in Al Jabin, the picture was greatly complicated by land ownership, and particularly by the large and diffuse landholdings of certain families. Thus local group interests could be profoundly affected by the aspirations of individual landowners resident elsewhere, with different group affiliations.

Varisco (1983) made an overview of studies of the link between type of water source and tribal organisation within a study of small-scale irrigation management in the YAR. In his case study of a Highland spring system, Varisco demonstrated that there was little need for day-to-day supervisory activities as the irrigator was capable of handling the entire sequence of activities involved in irrigation by himself. Thus

although there was an elected official, the *wakil* (called - '*aqil*' in other areas) responsible for the solution of disputes, he had no decision-making responsibilities in the distribution process or production system. He was more the keeper of knowledge and history of rights. The lack of an authoritative role or position with major economic rewards for the *wakil* was a function of the viability of local tribal customary law for regulating water and land. He materialised when there was a conflict, and did not even necessarily live permanently in an area.

I found a similar pattern in Al Jabin. What is of interest is that I was never introduced to a *wakil* as part of our initial discussion of the suitability of a water project. Our facilitator was the local government representative, or the PIIC worker, who may or may not have been providing accurate information about the water source. My counterpart was also involved in the discussion of projects, and thus passed on information that he could get from others, but then had to present the information in a way that was appropriate to the debate, and in a way that foreigners could understand. It was to our disadvantage that we failed to make distinctions on the location of knowledge until bad disputes showed us their importance. They were not hidden from us, but we just never asked to meet them. It was our bias on styles of contact and information flow that stopped us from asking the right questions from the right people. Because we initially failed to understand the types of local representation, we could not initially participate in a forum that reflected the changing politics in water management.

Both Varisco (1983) and Mahdi (1986) showed that, while local groups did maintain allocative roles for coexistence, they turned to a 'supra-group' for 'supra-community' problems. If the problems were infrequent, this procedure for settling disputes might actually preserve cohesion. However, frequent and/or violent conflict rendered the tribe unfeasible. Varisco (1983) noted the work of Wilkinson (1977) and Fernca (1970) who agreed that tribal political organisation was unlikely to be able to cope with problems

of cross-group communal organisation and upstream- downstream water conflict. Some of these problems could come from new technology, and others might be the normal opportunism that did characterise tribal society in the YR. The problem for Al Jabin in the mid-1980's was the change and uncertainty in the provision of this 'supra-community' legal role, between the new centrally appointed *mudiir-al-nahiyya* and traditional adjudication from religious and sheikhly elites. A critical question for us thus became which projects would provoke this 'supra-community' conflict. I came to understand that springs and other water systems were not inherently fraught with disputes, only those which provoked 'supra- community' tensions.

6.4. CHANGING TECHNOLOGIES IN WATER USE IN RAYMAH

Water was a scarce commodity over most areas of Jabal Raymah, and most of the sources were in use for irrigation. Irrigated crop options depended heavily on local microclimate, as well as availability of irrigation water, sharecropping controls and access to labour and markets. This section is compiled from field observations and village surveys, 1985-1987.

In the 1980s the most important innovations in water technology in the YR were pumps, pipes (rubber and galvanised iron), and the expansion of well construction technology. Most crops were irrigated through flooding of bunded plots, or by bunds around individual trees. There had been no experimentation with sprinkler or drip techniques. Drip technology was marketed locally, but was expensive, with polyethylene pipe commanding almost the same price as galvanised iron pipe of the same diameter. Roads and vehicles had also led to substantial transportation of water, both for domestic water supply and to maintain high value irrigated crops like qat (village surveys, 1985-1986). There was also innovation in ideas - the acceptance of the

idea that water could be transferred by pipe rather than carried by women and donkeys was new and still controversial for some leaders.

Small-scale expansion of irrigation through excavation of new springs and seepage points was found on the upper slopes, expanding coffee, qat, fruit and vegetable production. On the hotter, lower slopes, small petrol or diesel pumps were used to lift water from wells or groundwater streams to irrigate fruit, vegetables and sorghum.

Although borewells received much attention by aid donors, these were rare in mountainous areas like Raymah, for reasons of both access and geology. Three borewells had been drilled in the foothills on the western mountain slopes where access was reasonable. One was developed, although it only gave a low yield of 10 litres per second: one was dry, and one was still capped, more than six years since it was drilled (apparently because of uncertainty about which agency would complete it, and confusion about which settlements it would serve).

More important for Al Jabin was new dug well construction: in recent years there had been both limited horizontal tunnelling⁶ and better construction of vertical wells. Better construction of vertical wells included lining of hand-dug wells (previously unlined in Al Jabin), using stone for large diameter wells tapping poor groundwater flow, or reinforced concrete ring linings in sites of better groundwater and reasonable road access. In the past, hand-dug wells were only an occasional feature of the upper mountain slopes, but were expanding: usually they tapped throughflow under the terraces, or colluvial deposits, in wells typically 10-30m deep. They were more common in wadis, where they ranged 5-30m in depth. This trend of well expansion offered private access to water on privately owned land. In both wadis and on mountain

⁶ Deep horizontal tunnelling for infiltration galleries was not relevant in the hydrogeology and topography of Al Jabin.

slopes, expansion of hand-dug wells may bring greater competition into available resources, and influence existing spring and stream flow, long before borewells arrived.

In Raymah in 1985, however, so far pumped wells had only expanded in one wadi, Wadi Al Ariade, which ran into Wadi Sirhan (village surveys, 1985). The proliferation of dug wells in this area, with no regard to spacing, had already caused drawdowns in the groundwater, affecting all irrigation farmers in the wadi, and the traditional domestic water sources. Water level depths were already typically 20-30 metres deep in the upper part of the wadi, and 4-20 metres in the lower wadi. Some irrigators had sunk ringwells and operated diesel pumps, but small farmers using petrol pumps operated these from within hand dug wells, and faced ongoing excavation and operation problems as water levels changed, just as in India from the mid-1980s. Irrigation farmers nearest the traditional drinking water wells had overcome problems of falling water levels by constructing storage tanks near their pumped wells, from which villagers could take domestic water. In this wadi we were offered sites on private land for the development of wells for drinking water development, with the suggestion that the owner could continue to use some of the water for irrigation (field surveys, 1985). However, elsewhere such wells had occasionally been reappropriated by the owner and used for irrigation only, and this fear was voiced in Al Jabin. We did not preclude the joint development of wells for irrigation and water supply, but would only consider this in areas where agreements could be properly executed and maintained – and we were never able to get such an agreement.

Pumps require power, and projects involving pumps were popular since a generator could also be used as a source of electricity for villagers. In 1985 there was no grid development of electricity in the YAR: in Al Jabin over 75% settlements had their own electricity generators, with connections maintained only on regular payment of a monthly rate. Individual households could operate a small motor if there was no village

system. Thus the integration of a generator into a water project was of great interest to villagers, especially those currently without electricity or those who disliked the tariff levied by a private operator. The presence of a generator within a water project could also make collection of funds for maintenance easier, since charges for electricity and water maintenance could be collected together.

Pumps also enabled the lifting of water back up a hillside, from cisterns or streams, thus enabling individuals or groups to utilise water that may previously have been unutilisable. However, they were expensive, and people did not like leaving them in situ in parts of the mountain some distance from settlements for fear of theft or damage. By 1985, pump lifting of water for irrigation had only expanded on one perennial stream rising and flowing through what appeared to be a boundary zone between *uzlas*. Small petrol pumps were in use, with farmers resident in the locality.

There were a number of perennial streams, supported by groundwater, on the lower slopes and valleys in Al Jabin, and their utilisation was highly individual, depending on their hydrology, local settlement density, land tenure, and whether cultivable land existed by the stream or some distance from it. My first differentiation was between streams that rose and disappeared within relatively short distances, and those which flowed continuously through several 'territories'. In the first case, offtakes were permitted, and had either gravity offtake canals or an irrigation rotation in situ, depending on local topography. The potential for such water sources to be renovated and used within a drinking water project would depend on the relationship between the irrigators and the village(s) to be served. In some sites, streams had been developed into a piped irrigation system supporting coffee irrigation. All such situations could arise from classes 2 and 3 of Al-Mawardi's classification. Streams which flowed through several villages were utilised only for domestic water supply and associated micro-irrigation, except where all the villages benefiting from the streams were also

involved in irrigation. Such streams could fall under category 1 of Al-Mawardi's classification. We did not anticipate very large expansion of piping or pump lift schemes for domestic use on such streams, because of such complex traditional rights to their usage. The wide variety of agricultural and settlement conditions influencing streams, made them a difficult water source for which to state general principles of use, even within one district.

Piping probably had the biggest impact on water use on the mountains of Raymah, especially cheap rubber piping, which was used to carry small amounts of water considerable distances. While homesteads near streams drew small amounts of water from the flow, the main expansion had been in the excavation and use of small seepage points. The usual technique was to construct a small cistern by the seepage point, with a pipe leading from the cistern which was opened as required. The main impact of this activity was to decrease the total volume of seepage down the mountain. Water levels in some wadis had fallen, and it seemed that subsurface drainage lines were changing, leading certain wells in lower wadis to dry up. While road construction, drought and deforestation were all affecting the groundwater resources of the lower mountain slopes, the private expansion of irrigation up mountain has also had an important impact.

Clearly, there was considerable innovation and generation of new customary practices in water use, and some very subtle interpretations of guidelines taking place to enable this expansion. These changes were not simply a predictable response to market opportunities, rather they were possible because of the influence of local decisions given the scope of customary law. Many of these developments lay within an areal configuration allowing issues to be decided by villagers and their local representatives. However, I also suspected the influence of certain landownership patterns, where innovations were allowed on a day-to-day basis because that land was

farmed by powerful families, either directly or sharecropped. Thus the negotiation that could take place for individual smallscale irrigation development was much more flexible than that which could take place for collective domestic water supply improvements.

I also found that considerable private water markets existed in the YR. They existed in situ, for example where expansion of water for irrigation by pumping has supported separation of cultivators, water owners and pump owners, with complex sharecropping arrangements (see Makin, 1977). They also existed spatially through the transport of water, both for irrigation and domestic supply, and it was these transport markets which were strongest in Al Jabin.

6.5. PLANS AND INTERVENTIONS FOR DOMESTIC WATER SUPPLY

6.5.1 The visions of the LCCD

The plans for domestic water supply improvements generated by the LCCD are shown in Tables 6.1-6.3: they focused overwhelmingly on rainwater harvesting and spring development, with potential borewell developments rating surprisingly low. This limited conceptualisation of the potential role of borewells was, I think, partly due to appreciation of their limited potential until more roads were built, and partly to the low yields seen to date from borewells developed in the western foothills: costs may also have been a factor.

As far as we could ascertain from sites known, perennial streams fed by springs were referred to as springs in the plans, in keeping with Al-Mawardi's classification given in section 6.3. Hand-dug wells did not figure in the plans at all, although they were in use for domestic water supply in most of the *wadis*. This is presumably because

of the unreliability or paucity of yield in all traditional wells known to date, so that borewells were specified in preference. Throughout our work, we had to move between source development perceived as possible in this budget, and those perceived by ourselves and other government officials. We found that the local budget focused on cisterns and springs that were mainly seepage points rather than streams.

TABLE 6.1 Percentage of projects proposed for development from different water sources, (source LCCD budget plan 1985)

Water sources	% projects
Rainwater harvesting	48
Springs	50
Groundwater borewells	1
Water trucking	(1 project)
Total number of projects (192)	

TABLE 6.2 Percentage of villages in plan served by proposed sources, LCCD budget plan 1987-1991

Water sources	% villages
Rainwater harvesting	42
Springs	47
Groundwater borewells	11
Total number of settlements (428)	

TABLE 6.3 Range in settlement numbers in proposed projects, LCCD budget plan 1987-1991

Number of settlements in project	% projects with a certain number of settlements	
	Rainwater harvesting	Springs
1	56	44
2	16	24
3	19	15
4	7	1
5	3	2
Greater than 5	5	5
Maximum number in a project	10	10

Borewell projects included between 1 and 6 settlements, with 3 as the modal size

The tanker to transport water is worth highlighting as it later became a means for some representatives to criticise Oxfam as people took sides during a serious conflict that broke out. Purchase of a water tanker for Al Jabin was actively promoted by the PHC Hospital director (and powerful local sheikh and LCCD member), and this may actually have been one of the incentives to let the Water Unit start up. During a field visit by the UK Oxfam Director, this sheikh tried cleverly and strategically to put public questions to him about buying a water tanker, which he later also asserted was an agreement by Oxfam and the Unit, as another example of our unreliability. However, myself and others thought it was an untenable operating cost to shift onto the LCCD, and feared it could end up in private hands after the end of the project, apart from being uncertain where it could transport water from on a daily basis. With hindsight, I came to wonder if we should have supported this, although it offended all my own cognitive norms of locally managed water projects.

Rainwater harvesting projects accounted for 48% of the projects listed, and encompassed 42% of villages to be benefited in the plan. Over 50% of these cisterns were for one settlement only, but surprisingly, the remaining 44% were supposed to assist more than one village. We were never asked to help with technical assistance or funding for cistern projects, so we had very little information about how several settlements could share such small amounts of water. I presumed this was only possible where the 'settlements' were extremely small, in fact almost individual family units. Also, it was rare in Al Jabin for a village to be totally dependent on cisterns, except in certain mountain locations within a restricted or poor groundwater catchment. Usually drinking water was collected from a spring, even if this was several miles away. With the advent of roads, drinking water was often trucked up to villages. Cisterns were more commonly used for watering animals and washing clothes. Thus the expansion of cistern projects was probably seen to expand the amount of water locally in general,

especially on a seasonal basis. Cisterns had been improved with relative ease, albeit a lot of expense, elsewhere in Yemen under Oxfam assistance (Merabet, 1985). They were rarely sites of dispute, but were disliked by agencies because they provided limited or unreliable water supplies, and often had major quality problems from faecal and animal contamination, could have bilharzia risks and suffered from siltation. However, sometimes they were the only option.

The prospect of small dams across valleys was raised by some representatives. However, the most suitable sites in Al Jabin usually had considerable agricultural land at the site, and the cost of purchase would make such projects unworkable.

Most of the Water Unit work was therefore proposed for springs, which were the water source preferred for domestic supply. In the planning documents, 49% of projects listed also required pump lifting of water. Gravity based projects were proposed more commonly on the western slope of the mountain, whereas pumped projects were more typical of the eastern part of the mountain. While there were influences of political representation and technical understanding present in these plans, they gave an indication of the ambitions and concerns to be faced from the side of local representatives.

6.5.2 Visions on the possible from the Oxfam Water Unit

As Unit staff, we visited the village first without per se accepting the technical choices listed for water supply improvement. Our approach as outsiders with different technical conditioning, was to look also at options on all streams, and for more hand-dug wells and dams, as well as systems included on the list. Through this survey work and discussions with water users, we also came to understand more about which water sources would trigger disputes if they were proposed for further development, and also

which had what we at first considered insufficient water to justify investment (less than 40 litres per capita per day - although villagers were often sure the investment would be worth it).

We thus hit problems of lack of visible activity in the first year and a half, and none of the bigger projects in the LCCD plans gained approval. Through surveys we did find springs that could support improved supply through smaller improvements, which were often easy to recommend. However, as these improvements were often quite cheap to do, we did not do them - villages could do these themselves. Such recommendations were a task we felt we could and should do, but they did not enhance project visibility.

In the upper part of the mountain, where springs were usually small, most springs had been developed to provide a small collection chamber for domestic water. The quantities of water involved were very small, from 0.1 litres per second to less than 0.01 litres per second, with many springs in this lower range (field surveys, 1985). At some springs, water was conveyed by pipe to a collection chamber near the village, with an open pipe for the outlet of water. If any surplus seepage was seen as adequate for irrigation, it was collected in a small cistern for irrigation.

As a spring flowed continuously, most collection sites were muddy and dirty. Many villages had taken some steps to improve their spring sources. The simplest were improvement of the collection chamber, and concreting the area around the spring. If water and space were adequate, there could be attempts to provide a place for washing facilities (Howrah and Gotto surveys, 1984). In some cases water was piped from the spring into houses. These improvements had originally been financed entirely by the villagers.

Our proposals were thus for two kinds: improvement, and construction of new sources. In several cases we were asked to improve the design and operation of existing springs. The commonest design faults were:

- 1) inefficient construction of the springbox so available water escaped;
- 2) pipes of too narrow diameter, so that friction losses were too great for the scheme to function properly;
- 3) zig-zag pipe laying, increasing friction losses and increasing the risk of air blocks;
- 4) uncovered intakes so that water was easily polluted;
- 5) inadequate filter at intakes so that pipes became blocked;
- 6) poor drainage facilities around the supply point;
- 7) limited storage so that collection was time consuming.

All such improvements on springs were easily undertaken as long as all regular collectors of water could be supplied by the scheme. Negotiation was required if there was a loss of irrigation water through the renovation, or of land to the project, and this depended on the relationship between the irrigator and the villagers. With small water supplies, the irrigation income loss was small, especially if the irrigated production was sharecropped. Compensation could be arranged in money, land or water elsewhere.

Commonly, however, villagers looked for additional sources of water to increase the quantity of water available to their village. This became more problematic when it involved liaising with other irrigation interests, or claiming rights on finding a new source of water. Typically, villagers looked first for a new water source on unoccupied land that lay within the territory of the village. Sometimes sites were deliberately excavated to search for water, but several had been exposed through road construction. Again, we found no problems providing the excavation took place on unoccupied communal land within village territory. The problems always broke out in the boundary areas.

On the lower slopes of the mountain, the springs were relatively larger, and were more commonly ponded directly into cisterns for communal irrigation, based on a

rotation system. These springs yielded in the range 0.2 -2 litres per second (villages surveys, 1985). Domestic supply was taken either directly from the cistern, or from the spring seepage above (for example, Matlas survey, 1987). We thought, from our western technological training, that these cistern supplies could be augmented by: concentrating spring flow; lining the cistern and canal; and increasing storage to utilise all night flow. The water could then be piped or pumped to village, as the terrain required. It was these projects which proved most troublesome to develop, however, because of the complex interests and numbers of people involved with them. However, disputes were often not associated with water access and water rights *per se*: they could often be opportunistic.

For example, occasionally members of villages some distance away might have land irrigated within a system, and insist on benefiting from any associated new drinking water project (Merabet, 1985). Proposed changes were also an opportunity to challenge the village representative and continue old feuds. They were also an opportunity for groups or individuals to lay a claim to the entire resource, or challenge an older legal judgement that some villagers felt improper. Thus the problems with irrigation springs were not that their rights made them inherently unworkable for the introduction of piped drinking water: it was rather that particular conflicts could crystallise within such projects.

In fact, I came across two instances of irrigation and domestic water supply working quite well together (Gotto and Howrah village surveys, 1985), and we suspected there were more examples in the district. These were both situations where considerable flows from large springs were piped around coffee terraces, and where differential domestic uses were permitted, depending on the relationship that the spring developer had with the villagers. In all cases, villagers were either allowed regular daily access to the irrigation pipes, or weekly access to use flows on Friday, the day of prayer. For

example, in one system women from certain villages were allowed to wash clothes using water from the system, but not to collect household water daily, although they were allowed use of the water for all purposes on a Friday. Other villages or households were allowed to use the system for all domestic uses every day, but at certain times.

In another case whole villages were allowed to take drinking water from the spring system. In one case, we constructed a tank for a village that stored water from its spring, with regular topping up from a local irrigation pipe network (Gotto village system plan and construction, 1986), and from a local stream used for irrigation by villages downstream. All water in this case came from within one *uzla*. While there were regular arguments between families and villages, we thought that differences were reconcilable because all fell in one tribal territory⁷. It seemed feasible that a spring developer might allow the combined use of water for domestic and irrigated use if he had some economic leverage over villages through the operation of the system. However, where a group used a source for irrigation, and source improvements might benefit people now in another village, combining domestic and irrigation uses in one source was much more difficult, and a private developer might avoid it.

The groundwater streams in Al Jabin seemed an obvious source of projects, and we were asked to consider them by several representatives. Streams on the eastern slopes tapped the major part of the groundwater catchment, and surface flow ranged from as little as 0.5 litres per second to 50 litres per second on the lower wadis draining towards Wadi Rime. We had no data on seasonality of flow. None of the streams were regulated or dammed. However, we met resistance to development for all groundwater streams, except for those with very localised flow and limited irrigation development. As soon

⁷ However, there may have been private commercial contracts and financial exchanges not known to us, since this fieldwork was action-based rather than observational.

as we examined streams in use for irrigation for potential piped domestic systems - whether there were complex rotational arrangements within a village, or a sequence of irrigators along a stream - we met with resistance, even though we argued that there was surplus in the scheme. Large pump lift projects (lifting water several hundred metres through a sequence of pipes) were particularly controversial, as they were seen to help villages that had no family links with wadi dwellers. (Meswar and 'Oden village surveys, 1985).

We had similar experiences of disagreements around wells. Although the council plan always specified borewell development, we persuaded them to consider renovating hand-dug wells in some sites, as this land was sometimes the only communal point in the otherwise privately owned terrain. The only well sites we visited that were not immediately controversial were in *wadi* sites where terrain made agriculture unviable: where they lay clearly within an *uzla* or related group of villages: and where the village sites were near the wadi, and thus usually incorporated the wadi within their territory (Wadi Ibrahim village survey, 1985).

6.5.3 The struggles of territoriality on communal, unoccupied and boundary land

I came to the conclusion that virtually all types of sources could be worked with in Jabal Raymah, for irrigation or very small consumption of domestic water because local customary practice was actually very flexible. This was particularly true for small-scale irrigation offtakes, which could be developed easily within village territory, through family negotiation or private land ownership. New uses were being introduced on private land, and projects were implemented on clearly defined village lands. The main source of discord and delays in projects was resource management opportunism, where an individual or group made a claim to a source which was disputed or to which

they had no historic right. Sometimes the dispute concerned only one source, but a dispute could also be developed as a protest against the actual private appropriation by an individual or group of other water users nearby. However, the most serious disputes blew up over the question of rights to water development in 'communal' 'unoccupied' land. Also, it seemed that while most technologies could be used to develop most sources on private land, flexibility reduced greatly once we were dealing with communities. Territoriality was the key issue of how water sources could be used, with jealous protection of rights to water usage.

This raised the difficult issue of what constituted 'unoccupied' and 'communal' land on a mountain, on which we needed more research. *Uzlas* on the mountain had clear boundaries, which often ran along *wadis*. These *wadis*, however, were often conveyors of considerable amounts of water. Frequently these communal lands were steep sections of mountain lying between the village and the boundary, often at some distance from the villages. It was common for an *uzla* to have springs and groundwater streams rising on communal land which the villages of the *uzla* did not use because of the distance of the spring or stream down the mountain. Often one upstream *uzla* allowed access by downstream *uzlas* on a practical basis, but still claimed the right in theory to dispose of those sources as they wish. This was a pragmatic solution, as a downstream *uzla* or village might lay violent claim to the water source if access cannot be negotiated and 'allowed'.

Communal land was usually uncultivable land, by virtue of its steepness, inaccessibility or shallow soil. Such minor problems, however, rarely defeated a skilled climber and terrace builder. It was possible for terraces to be thrown up in a short period of time and defended as a private claim to communal/unoccupied land, and this seemed fairly common practice in Al Jabin where water is involved. (Field observations, 1985).

Until recently, such tensions were resolved practically, in the way that Mahdi (1986) suggested. However, the pressure on supplies, and the new opportunities offered by pumps and pipes put these disputes back on the agenda. The issue was whether the access permitted pragmatically by another *uzla* or landowner had a force of law over the theoretical rights to disposal and use held by the traditional controllers. There had been several such disputes being resolved by 'supra- community' representatives in favour of the irrigators who had been permitted pragmatic access, and not with the customary tribal rights of control. These proved contentious because of family or commercial ties between the supra-representative and the irrigators, and also because of poor circulation of information among illiterate villagers on what was been allowed in these new rights of access. The following sub-section gives a summary of a water dispute that escalated into a conflict, that came to encapsulate all these pressures of change, and in which the different cognitive world, expectations and strategies of different groups burst out into full public politics.

6.6 MATLAS: THE GENEALOGY OF A WATER CONFLICT

On May 10 1987, shots rang out, fired into the air over the spring at Matlas. Within 10 minutes, much of the spring box had been pulled apart. Within half an hour, the path to the spring had also been pulled down. No one was hurt, but there was an organised show of aggression that made everyone leave the site at this point. Within 24 hours, a well-known sheikh and director of the hospital was put in jail for his association with the conflict (some say this was as representative of the perpetrators of the violent measures, others because he was a party to it and did not stop it).

The Water Unit first became involved in Matlas in November 1986, when the President of the LCCD asked the Unit counterpart 'Mohammed' (pseudonym) to do a first design and estimate to improve supplies in the village of Matlas, at a time when I was away. He duly did this, for a project costing about 120000 rials⁸. The LCCD president announced publicly that the LCCD would help Matlas and proposed to split funding costs 50:50 with the villagers. Everyone was so confident that they advertised for a contractor in the newspaper.

Matlas village met many of the criteria for support from Oxfam. It had about 300 inhabitants settled in two hamlets, whose main water supply was a spring about 1.5 km from one village and 2 kilometres from the other. Because of distance and terrain between villages, the lower village had a cistern used for washing and watering animals. Apart from distance, a critical problem was the steep terrain near the spring, and the narrow path that skirted the edge of a chasm to get to it: two women were said to have fallen to their deaths trying to carry water here. The spring was excellent in terms of quality and relatively acceptable on quantity, yielding about 15 litres a minute. The village wanted a pipeline supply from the spring to the village. Several meetings were held in the village to discuss the project: following project procedures all families and village representatives signed their agreement (Matlas village survey, 1986).

There were technical challenges that made the project expensive. One concern was over a lot of suspended pipe work necessary and the other that a small pump might be necessary to lift water near the spring. Off-road transportation costs were high, but these had already been covered by money collected by the villagers who had already deposited 50000 rials with the LCCD. We submitted the project to Oxfam in February

⁸ The exchange rate at this time was 10 Yemeni rials to the pound.

1987, who became involved partly because no contractor had appeared and the rial began to lose value, so that the LCCD budget was insufficient.

However, the spring lay in an *uzla* boundary area, and the struggle to claim water from the spring soon revealed itself. Almost immediately after the project was announced, men from the villages below Matlas protested that the spring development might affect their irrigation. Seepage and overflow from the spring fed into a stream in the *uzla* of Bani Bil Hood, where it was used to irrigate coffee. Then it materialised that the land around the spring did not belong to Matlas village: it belonged to a settlement in Al Jabin *uzla* above it. This group said they were willing for Matlas to use the water providing that Matlas wrote a letter guaranteeing their land rights. The dispute went to the new *mudiir-al-nahiyya*, the new state appointee, who in February ruled in favour of the Matlas project continuing. One man involved in the dispute from Bani Bil Hood was also imprisoned in the local lock-up for a month for trouble-making.

I had seen the possibilities and problems purely as water supply issue, from physical perspectives. The stream collected water from a fairly wide stretch of mountainside. I argued that proper lining of the springbox and use of pipes for water distribution would stop diffuse seepage and increase flow, and we also offered to consider lining some of the local irrigation canals. However, the issue was not the quantity of water; it was about who had access, and might claim a share of the source if new entitlements were given. It was during these field visits that I met the *wakil* for the first time, who materialised to advise in the conflict, and also later in Sana'a.

Two critical actors were brothers in a sheikhly family who owned land in Bani Bil Hood, and who were also the representative sheikhs for Matlas village and villages downstream in Bani Bil Hood *uzla*, referred to here as Abdu and Saeed Al-

B (pseudonyms). Both were members of the LCCD, although neither was Chairman in 1985. One was also director of the hospital in Al Jabin linked with its primary health care work, also supported by Oxfam. Whatever these brothers felt about the project, the representative for Matlas could not deny the interests of the village he represented in public. Possibly they thought they could control outcomes if any dispute went to the old adjudication forum they could influence. However, the dispute was also becoming a struggle between the old and new political systems.

By early March 1987, the conflict had moved to another forum. Representatives of all villages and *uzlas*, and ourselves, were in the capital Sana'a, trying to contact both the national president of the LCCD, and members of the governors' office. After realising this, everyone convened in the house of the LCCD Chairman for the Sana'a governorate. Then an older story materialised. It seemed that some 3 years before, there had been a separate dispute about the spring between the villagers of Bani Bil Hood and Matlas. Abdu and Saeed Al-B were asked to settle the dispute, and took 40000 rials from the villagers of Bani Bil Hood as a fee. They wrote a paper saying that the land around the spring was the property of Bani Bil Hood (although it was seen by many to belong to Al Jabin). Many villagers did not know the contents of the paper because they could not read. Several did know, but were too scared to be identified as ringleaders until the dispute of 1985 started to escalate.

Although the villagers of Bani Bil Hood at first resisted the water project, they then said they would agree if Matlas village paid 50000 rials for a right to use the spring, as a kind of compensation. Abdu Al-B had been in the Governor's office making the case for Matlas to pay this money earlier that day. Matlas villages said they would not pay. Abdu Al-B attacked Oxfam further at this meeting: it appeared he had not realised that Oxfam was moving so quickly to help the project and had thought he could delay it within LCCD budget politics. He argued that the project

could not be approved because LCCD funds could not be released yet. We had not heard that yet (and he was right), but argued that if the scheme was approved in principle, surveys could begin with a view to the project starting. We also later found out that one reason for delay was investigations into financial mismanagement of local councils by their national council. January 1987 had been their first visit to Al Jabin and they had found financial irregularities under the previous LDA of which Abdu Al-B had been treasurer. In a long public diatribe, the project was attacked for not doing enough and failing to back proposals from the LCCD. (Project notes, 1987).

At the end of the evening, the Unit counterpart was challenged by Abdu Al-B, on whether he was working for the LCCD or working for Oxfam: he replied that he just wanted to get on with working. The following day the Matlas villagers were given the go-ahead for the project from the CLCCD administration. They estimated that lobbying had cost them some 20000 rials. They were given a letter saying that the project could go ahead unless the villagers of Bani Bil Hood could prove conclusively that the land around the spring was theirs. Oxfam supported continuation of the work, because they had been requested by the LCCD and CLCCD to begin implementation, and on that basis we began work. We purchased the pipes (gaining the warning from the Hodeidah supplier given at the start of the chapter) and had them transported to the roadhead. Villagers moved all materials down into Matlas virtually overnight in the hope to start work.

On the morning when I showed up to start the work (having sent my counterpart to finish other work elsewhere as I did think there might be a protest), the violence at the spring broke out. Abdu Al B was put in jail for two days. Al Jabin town went on alert with concerns over further violence, but things quieted after his release. He claimed later this was done to him as sheikh of Beni Bil Hood, until the instigators

turned themselves in. The story on the market was that he just wanted 50000 rials for the project to go ahead – which some local people saw sheikhs doing often as a fee claim in negotiation, and in the end was not ‘so major’ (although Matlas people remained angry). I was advised to stay in Hodeidah for a while, although I did return to finish my contract and the two other projects. Matlas villagers were left to reconstruct their spring, although they kept all the pipes we had bought in for the project. The Water project stopped in 1987, and one year later, its counterpart had still not been employed by the LCCD. If we had known at the beginning what we understood by the end the project might have worked. To this day, I do not really know if all the positive support stated in public only came because no-one believed we would start the project given our earlier slow record, as well as the belief the two sheikhs could control any background negotiation through their traditional power base.

6.7 CONCLUSIONS

Mountains are not only physiographic landscapes with complex hydrology, they are part of a social landscape, for which it is essential to understand property rights and institutional actors as well as the social structure of village life. land ownership and rights of access. The development arena of Raymah, with its extraordinary contexts of change, forced me into a new understanding of what non-government agency and key institutional actors could be, and that I needed a whole set of ‘non-elitist’ and non-scientific skills of seeing, listening and negotiating that I had never learned in my previous cognitive or scientific development.

I also had to learn to work with non-scientific elites and tacit knowledge, to work almost without science as I had known it. Switching to a perspective of

scarcity (what people could access through available social means) rather than drought (as particular forms of shortage and lack) also brought technology into a new profile. I could see technologies were complex to introduce or reform, not only because of their intrinsic material dimensions and properties or amoral non-neutral impacts, but because of the tacit knowledge involved to keep them functional in a world of scarcity dominated by a desire to get water. The supra-authority was not vested in any technical rules like well spacing – which were so obviously unenforceable – but in the social structures themselves. The social rules to keep water within an *uzla* acted to protect ‘social catchments’ to ensure water access within which they felt their water use choices were up to them. I learnt also that exchanging cognitive frameworks takes time, and must often also involve action, that forces real knowledge and strategies into the open. These skills went beyond what my formal technical training and participatory methodologies had taught me so far.

One could see too, how it was the rules around technology and information from its use that had driven the creation of scientific knowledge about the ecology and technology of the area, as Brook’s classification suggested could happen. The testing of the water rights categories of Al-Mawardi against adaptations around hydrology in Al Jabin vindicated them as cognitive tools for interpreting water management practices, and in studying water project options in Yemen.

The problem was not that there is no water management in the YR- there is a lot of customary law. The problems lay in the conflicts that economic, technical and political circumstances were creating in certain sites. This did not mean that no water projects could be developed. It became a question of distinguishing which projects lay in a likely conflict zone. This affected both springs and well developments. Understanding the relationships between villages involved in a

scheme was also critical, as was understanding the relationships between villages in the locality of the water source and those villages actually being served by the project. Thus the nature of potential opportunism needed to be considered in the early stages of a project and legal advice sought. Properly drawn up agreements at the investigation, design and implementation stages, involving all villagers and all local representatives were time-consuming but would prevent such opportunism. Such evaluation can also help limit the damage to the enthusiasm of villagers, and the reputation of individuals, that will be caused by a stream of potential projects which never materialise. The causes of escalating disputes can be studied, and solutions developed if an appropriate forum for local water politics is facilitated. Otherwise, in a situation of scarce resources, the donors themselves will be used as a resource. So much of the rhetoric of development before the 1990's was about transforming technologies and institutions in a normative direction. So little has been written about trying to work with people to transform technologies when wider politics are also changing.

The struggles of the project showed not only the physical water scarcity but emergent structural water scarcity in the actions of elites to determine water access for their own groups. The material in this chapter echo some of the findings of Turton and Warner (2002), whose frameworks were recently tested by others in Yemen - Lichtenthaler (2003) described a sheikh who stopped all groundwater development in his village. There was the first order scarcity challenge in the availability of water, and a second order scarcity challenge of social resources and adaptive capacity in their management. However in this study, the struggles around physical scarcity were already showing structural scarcity dynamics of the kind described by Homer-Dixon (1995), making second order changes in management very conflict prone. Within these changes lay a challenge not only to negotiate the

physical structures for resources use in a droughtprone area, but also the ability to redesign address equity and justice as it is seen locally. Choices of what new norms can work can only be evolved by a society given its developmental state, in which transformations in local and supra-local authority and capability are critical issues.

CHAPTER 7

SURFACE WATER DROUGHT AND STRUCTURAL WATER SCARCITY IN THE LOWER ODZI WATERSHED, ZIMBABWE

Neither the frugality of nature nor shortages of resources define scarcity...shortages due to poor harvests are not the same as scarcity, because it is the relationships between people that define scarcity...In traditional societies...shortages only equal scarcity when they became an issue of rivalry. Scarcity in the economic sense is related to the struggle for goods, which are scarce because they are an issue to fight over. This becomes the case in modern society, where desires are no longer restrained but freely expanded. Tijmes, 1998, p. 84

7.1. INTRODUCTION

Zimbabwe is the third and last of the droughtprone areas to be studied in this thesis: this case study focuses on the Lower Odzi watershed, part of the Save river basin crossing Manicaland Province in eastern Zimbabwe. The variable rainfall of this watershed, from over 800mm in the highlands to below 500mm in the hotter drier lowland valleys, came to be echoed in segregated settlement patterns and land allocation in the colonial period. This rainfall regime, in combination with physiographic features, generated a river network that was perennial in good years albeit with a strong seasonal regime. However, the same social mechanisms that segregated land access also restricted access to river water for irrigation, creating a structural water scarcity that limited access to water more generally, and not only in a year of surface water drought with low or zero flows. How such drought problems were conceptualised and acted against, and how hydrological analysis reflected these frameworks and ignored analysis of structural water scarcity – and how all this related with the wider structure of the state in Zimbabwe - is the subject of this chapter.

The state of Zimbabwe, and its colonial predecessor Rhodesia, has shown an extraordinary continuity in problem identification and technical norms in water development, across a country almost entirely under a seasonal rainfall regime, and

with areas prone to more erratic rainfall and drought that faced famine at certain times (Zawe, 2000). These norms evolved for the primary focus of land settlement zoning and profitable agriculture in segregated (white) commercial farming areas, accompanied by changing and variable concerns for smallholder agriculture largely segregated in communal areas (originally called native reserves and later tribal trust lands). Rainfall availability and soils were primary criteria in this zoning, while runoff data estimated from this data became a core technical parameter in water right allocation, and dam design.

The history of the state has moved from settler colony gaining separate identity from South Africa, to the British colony of Rhodesia marked by segregated land access, through a liberation war and independence in 1980 that led to the so-named socialist independent state of Zimbabwe. However, many of the earlier water agencies and norms simply continued despite these political changes until the major legal changes of 1998. Only then did a radical shake-up begin of biased and privileged water legislation, that underneath quite sound data collection frameworks, nevertheless gave very unequal water access to white and black farmers. Then a new Water Act emerged in 1998 to change strategic planning agencies, revised representation of users within a river basin framework and transformed historical water rights into licences.

Information for this study was collected between 1997-2000¹, at a time when water management was in transition under the new Water Act and Zimbabwe National Water Authority (ZINWA) Act. The research was completed before the advent of land occupations and laws supporting resettlement of commercial farms were enacted. By

¹ The study was undertaken within a longer-term collaboration programme between the University of Zimbabwe and the Wageningen University, known as the Zimbabwe Women, Extension, Sociology and Irrigation Project (Zimwesi) because of the departments involved. The programme supported MSc and PhD research – some by individuals employed in state agencies – as well as research by collaborating staff. Access to information and data was thus relatively straightforward and open, and local farmers were actively involved in the field research, while the programme itself was well resourced for research, also with vehicles, and computers. Virtually all research developed from actor-oriented perspectives.

2000, over 95% of white-owned farms in Zimbabwe were in the process of being acquired for land redistribution, but not all farms were broken up into smallholdings. However, there was still a commercial sector present and the so-called indigenisation of the agricultural sector will not make the problems discussed in this chapter disappear. Rather the new political pressures highlight the importance of promoting a 'smallholder' hydrology perspective' in future water resource management.

Information sources for this chapter included: the register of water rights for the Lower Odzi watershed; literature in the National Archives of Zimbabwe; computerized daily and monthly river flow records held by the Department of Water Resources (DWD) in the Ministry of Rural Resources and Water Development (MRRWD); and computerised monthly rainfall data available from the Ministry of Lands and Agriculture (MLA). The network of rainfall and runoff data expanded in Rhodesia from the 1970's particularly, but was fractured by the liberation war. In a number of cases, data collection did not resume thereafter. However, some of these older data series were used, when there was no other available representative data for that locality. It also draws on the work of associated PhD research under the Zimwesi programme (Bolding, 2004; Chidenga, 2003; Manzungu, 1999), MSc research (Zawe, 2000) and special research assistance (Smits, 2001).

Section 7.2 gives a brief overview of the Lower Odzi watershed. Section 7.3 examines the historical development of water legislation and agency development. This shaped the data that came to be collected in the public domain, and its relation with key cognitive institutionalisation about the nature of water problems and tasks of water legislation and agencies. This demonstrates how norms such as the prioritisation sequence of water rights and classification of water within public and private domains echoed the broader political focus on commercial agriculture as it became ever more significant in the economy. Section 7.4 then introduces one of the critical technical

norms adopted to study water availability - mean annual runoff. Technical norms tended to focus around the generation of averages that helped in certain kinds of agricultural planning, but looked less at problems of variability of water supply and risks of drought and crop failure for small farmers. Section 7.5 returns to look at the historical evolution of settlement and water right patterns, their implications in water use within the Lower Odzi watershed, and how this created key actors and brokers in contemporary water management. In this watershed there had been a complex abandonment and re-scheduling of water rights, through the lapse of older farm rights in the liberation war and the development of many smaller 'informal' off-takes in more recent decades. There were also a number of relatively old smallholder irrigation systems in the lower river reaches, which came in conflict with these more recent upstream smallholder irrigators at times of low flow. Section 7.6 studies the actual water availability and patterns of low flow and scarcity for water rights in the watershed, through what are quite conventional hydrological techniques previously unused by agencies responsible for water management.

The study concludes in section 7.7, that there has been a shift in cognitive norms, especially recognition of the problem of smallholder farmers in registering water rights, and of the stresses now emerging at low flow on many rivers, through over allocation and illegal use of water. However, there has been little change in basic technical norms that remain institutionalised within agencies, even while these agencies were transforming in administrative scope after independence. Hydrometric design (data collection networks) and data compilation methods still need changes if they are to address smallholder needs. There were various emergent problems for the 1998 law and the new organisations in this watershed when this field research ended in 2000. These may not only maintain stresses between commercial and smallholder farmers, but also leave dilemmas and tensions between smallholders and their representatives active in

new catchment management structures - for example between large and small permit holders and even between smallholders in different irrigation schemes. While the new Water Act gave a new platform for local agencies, the political and financial problems of the now underdeveloped and patrimonial Zimbabwean state have left little scope for new analytical study - except where external funding supported some of the new Catchment Councils. The challenge remains to find both resource monitoring methods and technologies that can develop more just and more reliable allocation and regulation in a complex river system, especially for smallholder irrigators.

My own cognition had already transformed by the time of this research, and changed further during its process. For the first time I was involved in research concerned more to understand evolution of strategy within public agency. This was very different to all my earlier work that was largely involved with looking at development objectives of agency and relevant performance. Working in a country with such relatively strong and centrally directed resource management agencies, with a strong history of legislation and legal and jural institutions in water, gave me very different research possibilities - both to explore conventional hydrological approaches, and also the whole concept of 'technology as legislation', not possible in the Indian case studies. Working with a critical mass of researchers, also many of them doing in-depth PhD research and often highly placed, also gave an extraordinary framework on which to reflect on these ideas, free of the institutional and academic politics that dogged often earlier research. Much of the work in the study presented here has also been written up as a book chapter (Vincent and Manzungu, 2004), as most published work this programme aspired to be co-authored².

7.2 THE LOWER ODZI WATERSHED

The Lower Odzi watershed encompasses the eastern tributaries of the Odzi river (see Figure 7.1): the Umvumvumu and Nyanyadzi rivers were particularly important rivers in this watershed and are the main focus of study in this chapter. The terminology to demarcate hydrological zones changed with the new legislation of 1998, during the course of this research. The Odzi river is a major tributary (since 1998 called sub-catchment, previously hydrological sub-zone) of the Save river (since 1998 called catchment, previously hydrological zone). For planning purposes the Odzi river was previously divided into three hydrological units - the Upper, Middle and Lower Odzi. In the past, a 'hydrological unit' was the lowest level hydrological planning unit for water resources planning. The study area is actually now a 'sub-sub-catchment' – a hydrological planning unit below the level where formal representation present in the five new Catchment Councils. Under the Save Catchment Council created since 1998 there is formal representation for the Odzi sub-hydrological zone or sub-catchment. The sub-sub-catchments or the old hydrological units, remain as areas only with managers or bailiffs that report to the catchment manager. From now on this 'sub-sub-catchment' is referred to as the Lower Odzi watershed.

The watershed covers some 2426 square kilometers, and includes several 'Natural Resource Regions' – the landuse planning approach of Rhodesia/Zimbabwe based on annual rainfall and soils (like India). In its eastern highlands, this watershed has Region II land originally scheduled for intensive farming under commercial (white) farms (rainfall 700-1050mm per year mainly confined to summer): this is the zone where all

² Most of the data analysis and archival surveys for this study were my own. Other researchers and assistants helped with compilation and computerisation of rainfall and runoff data and water rights, and a study of correlations between flows in tributary and main river systems.

the eastern tributaries of the Save rise. In the western and southern parts, the watershed has Region IV and V land scheduled for extensive farming – largely under communal lands (earlier called tribal trust lands, reserved for smallholder black farmers). Zone IV has annual average rainfall in the range 450-600mm year and is subject to frequent seasonal drought, while zone V has less than 500mm average rainfall per year that is also erratic and unreliable. These areas face uncertainty in addition to seasonal drought phenomena: irrigation has thus been important for sustaining and intensifying crop production, and smallholder irrigation was encouraged, initially also as a protection against famine as in India (Roder, 1965). The hydrological diversity across these areas can be seen in the rainfall figures of Table 7.1.

Table 7.1 Rainfall variation across the Lower Odzi hydrological unit

Raingauge site	Mean annual rainfall mm	Catchment location
Nyamabewa ⁽ⁱ⁾	745.4	Umvumvumvu river, old commercial farming area, hills
Umvumvumvu Cashel) ⁽ⁱⁱ⁾	504.2	Mid-Umvumvumvu, old commercial and smallholder areas
Mhakwe ⁽ⁱⁱⁱ⁾	474.5	Nyanyadzi, communal area

Calculated from daily rainfall records (i) 1945-1970/71; (ii) 1952/3-1994/5; (iii) 1963/64-1978/79
Source: Ministry of Lands and Agriculture

The site of Mhakwe in the communal areas had an annual rainfall as least as low as parts of India formally recognised as droughtprone. However, a few miles to the east, highland sites like Nyamabewa had higher rainfall, which in combination with cooler temperatures made production options quite favourable. Rainfall varies considerably from year to year and there may be cyclic patterns present. Figure 7.2 shows the annual rainfall recorded at Cashel Road raingauge in the Umvumvumvu catchment. Runs of years with lower rainfall are visible. The cyclone of March 2000 ended a decade of drier years, but also washed out or damaged river gauging stations along the river.

These facts had a significant impact on the settlement patterns and Land Apportionment programmes implemented during the colonial period. The wetter cooler zones had the earliest white settlement and registration of water rights: the earliest water right in the watershed is from 1916, along the Umvumvumvu (Water Rights Register). The Umvumvumvu, with its more perennial flow and better rainfall was exploited by white settlers much earlier than the Nyanyadzi, although Bolding *et al* (1996) showed a longer historical use of small furrows by local people that was never registered in water rights. The drier, hotter zones were scheduled as native reserves (later renamed tribal trust lands and finally communal areas, see Zawe, 2000), creating an ethnic and agrarian polarisation along rivers that became particularly strong along the Umvumvumvu and Nyanyadzi rivers. The rivers were a source for irrigation.

As well as extraction rights for commercial farmers, collective smallholder irrigation schemes were developed for groups of farmers along these tributary streams, and many small informal furrows were developed by local smallholder farmers, that were not registered for water rights (Bolding *et al*, 1996; Bolding, 2004). Seasonal and longer-term dry periods in rainfall created a seasonal regime in rivers, with periods of low flows. Surface-water drought became a reality not just from this seasonal flow regime, but also with eventual over-allocation of water rights and over-exploitation of resources relative to these low flow periods, resulting in competition for water. The historical date of grant of water rights prioritised rights to water at low flows—nearly always advantaging commercial farmers, and left fights and struggles between small black farmers in different parts of the watersheds (Bolding, 2004). At such times, downstream irrigators with formal rights in group irrigation schemes traveled upstream to close down the informal furrows of irrigators without rights (Bolding, 1997).

The Odzi river receives tributaries from the western and eastern parts of its watershed (see Fig. 7.1). However, prior to 2002, all water rights for agriculture lay

along the eastern tributaries – the Whitewater, Wengesi, Umvumvumu, Murare and Nyanyadzi rivers (Water Rights Register, Harare). The Umvumvumu and the Nyanyadzi have been the most important river systems feeding into the Odzi in terms of numbers of water rights and stakeholders. All these rivers consist of a complex network of tributary streams with the drainage network strongly affected by the hilly topography. Both the Umvumvumu and Nyanyadzi rivers have highly seasonal flow regimes and suffer from periods of low flows. However, plots of flow over time suggest that flows are declining. Figure 7.3 shows the plots of monthly flow volumes for the Umvumvumu river.

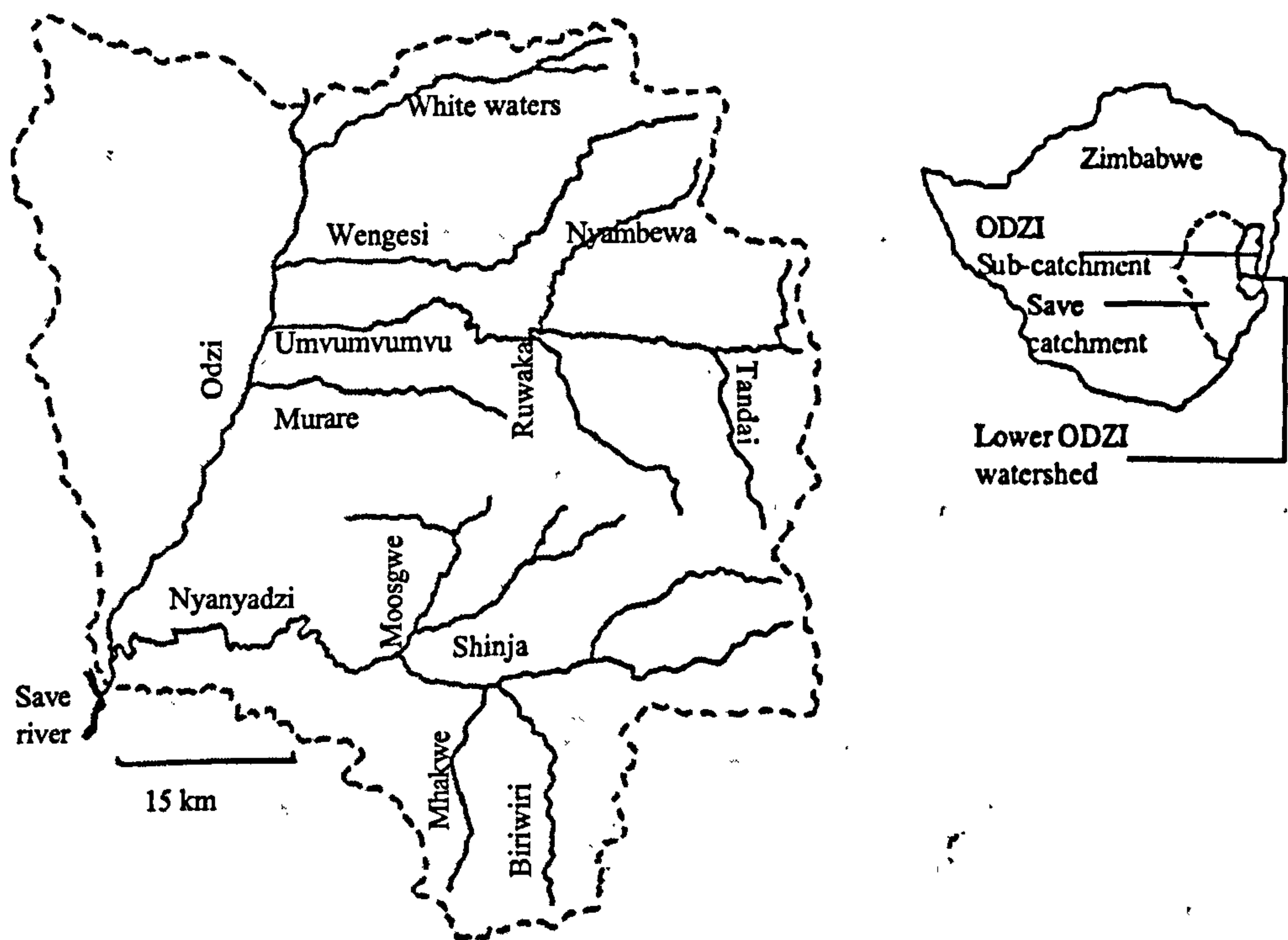


Fig. 7.1 The Lower Odzi watershed and its river systems

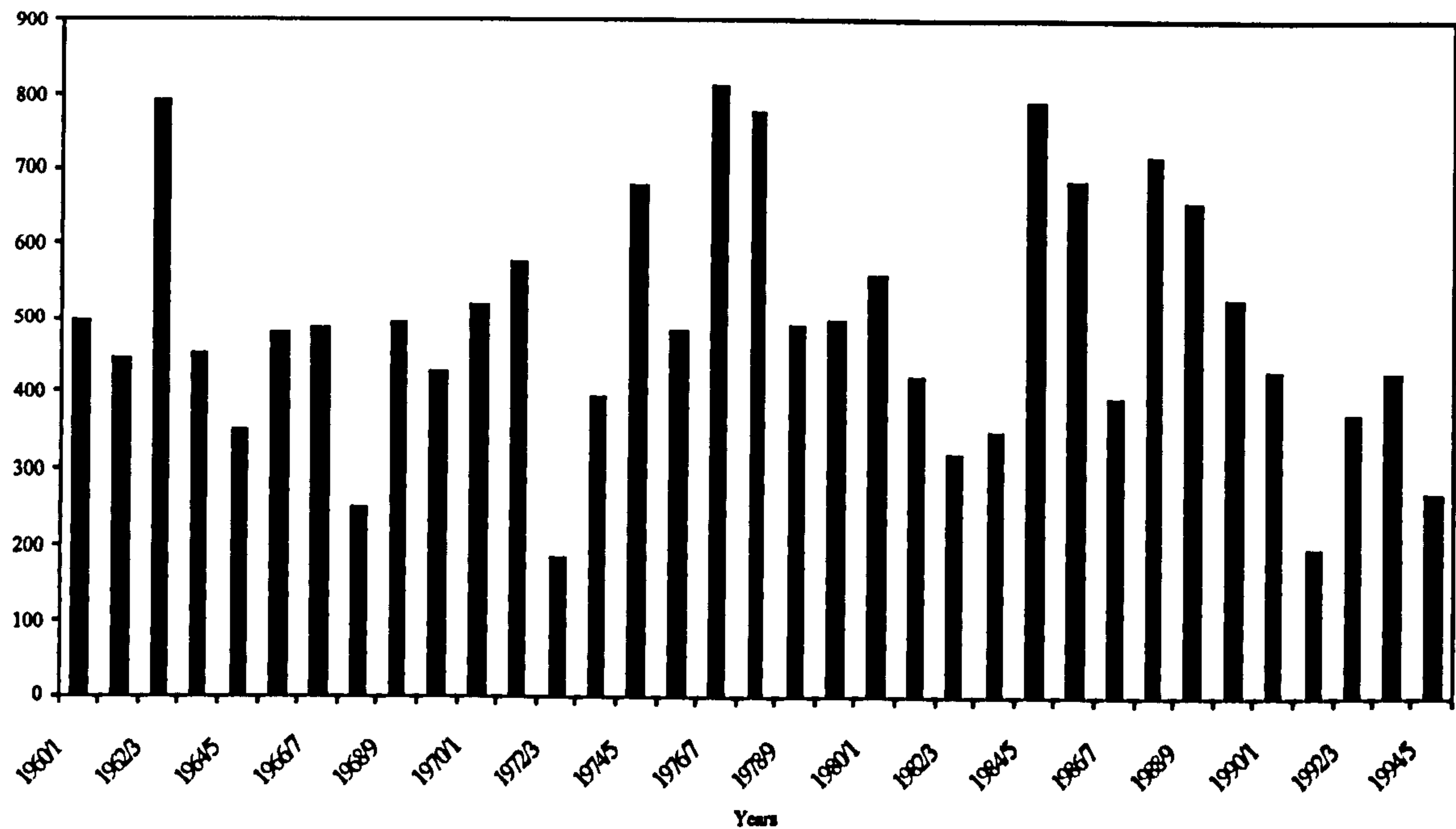


Fig. 7.2 Annual rainfall, millimetres, Umvumvumu raingauge (source: MLA records)

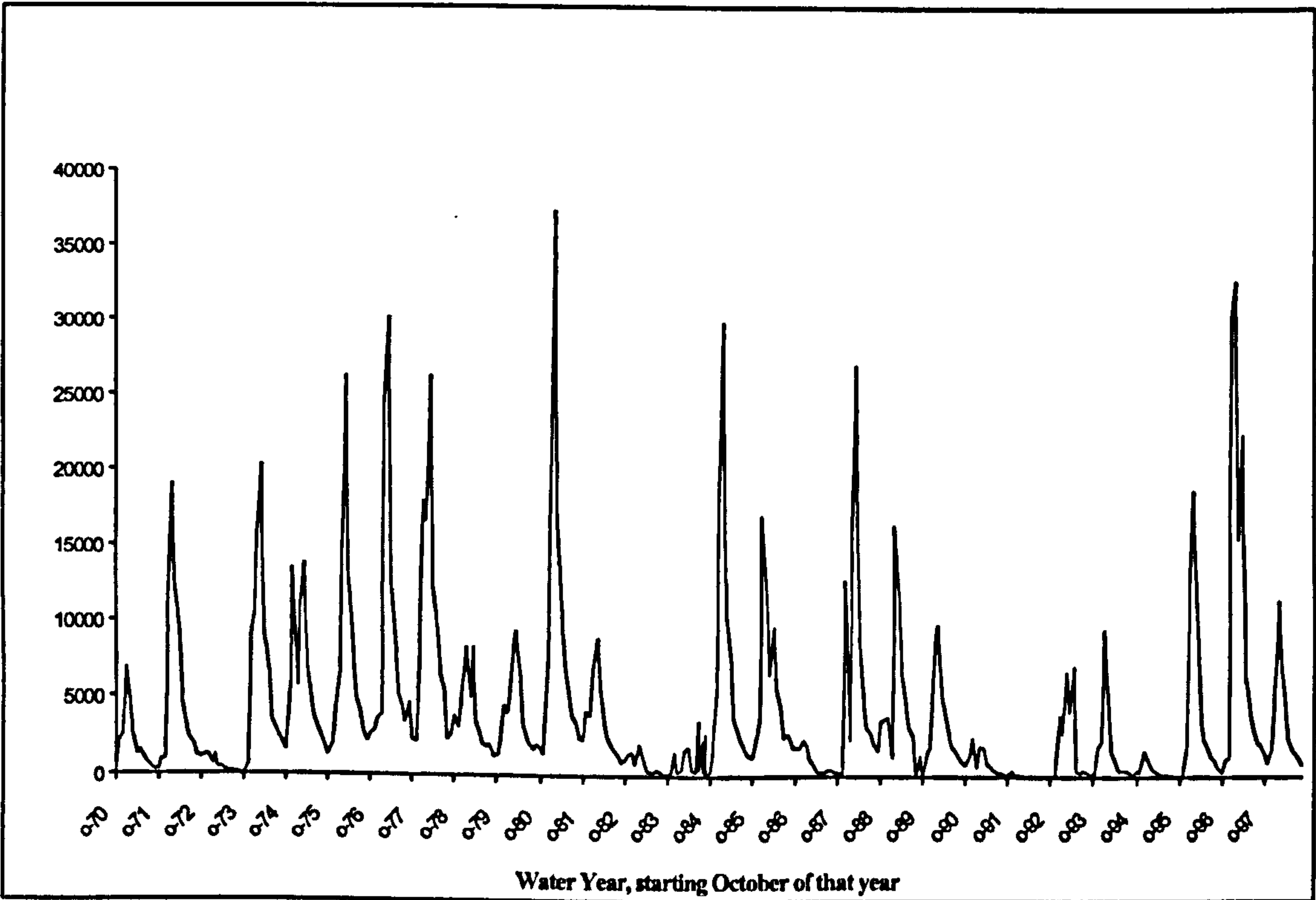


Figure 7.3 Umvumvumu river, monthly flows, 000 cubic meters E125 Old Cashel Road gauging station October 1970-October 1997 (source: DWR Flow gauging records)

There has been a change in both the availability of base flow and perennial flow and in the level of peak flows since 1980/81. River flow is also sometimes subject to a drop in flows in the months of December, January or February in some years as a result of rainfall patterns, and this drop has fallen to lower levels as flows have become more erratic. On the one hand, this change was influenced by the more variable rainfall regime that has characterised this decade. However, it was also undoubtedly being affected by the increased abstraction of flows and changing land use in the catchment. These changes were the result of the resumption of agricultural activities in the 1980's after the liberation struggle, a subsequent redistribution of land, population increase and a more intensified development of irrigation to support livelihoods in the area.

A similar picture of changing base flow emerges for the Nyanyadzi river (Fig. 7.4). Comparing the 1990's with the 1970's shows an even clearer decrease in peak flows.

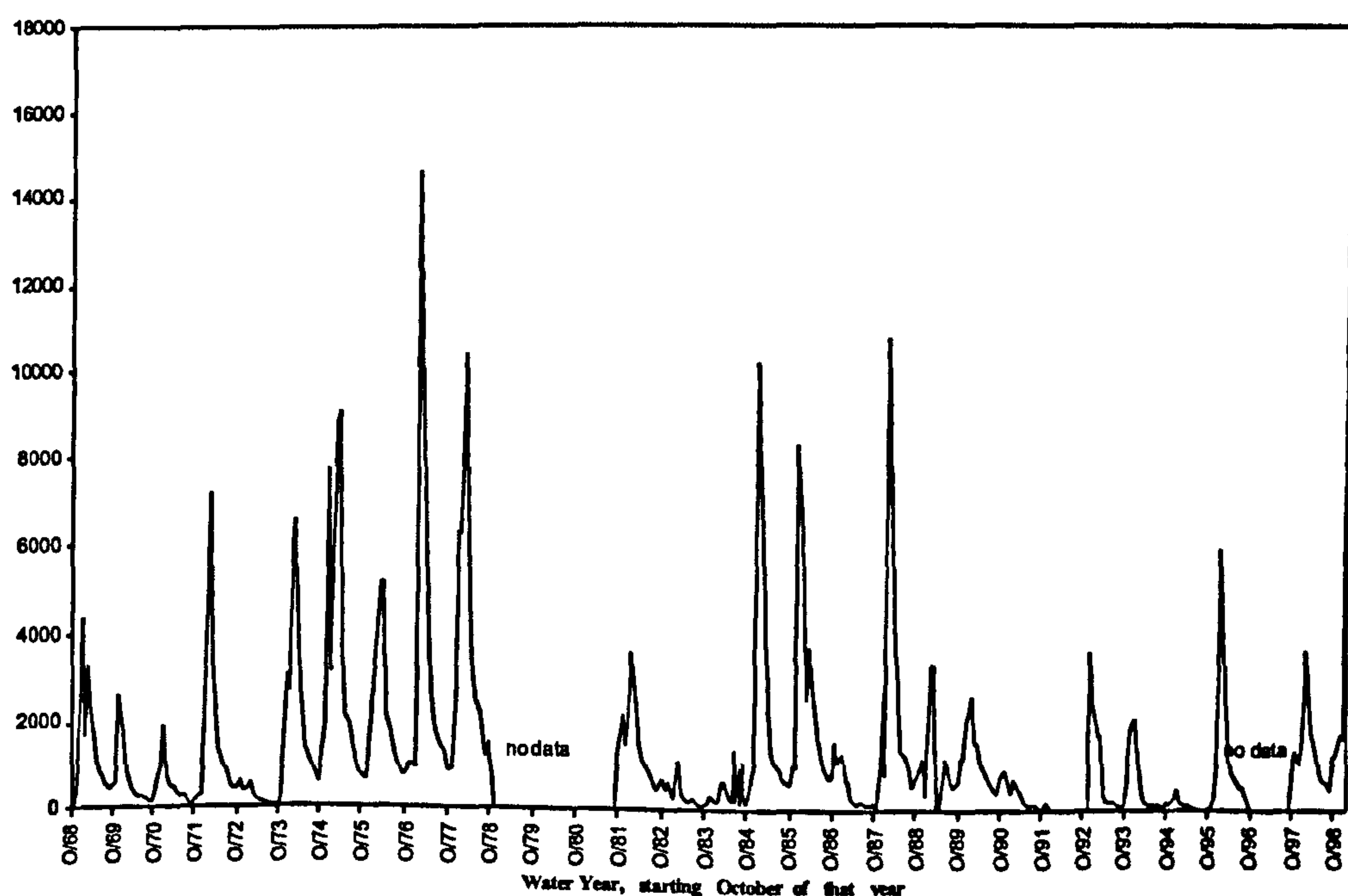


Fig. 7.4 Nyanyadzi River, monthly flows, 000 cubic metres, E121 gauging station, October 1966-October 1998 (source: DWR flow gauging records)

These hydrological fluctuations and uncertainties were the backdrop against which to study cognitive and technical norms portraying levels of drought and scarcity in the Lower Odzi watershed.

In data collection, Rhodesia/Zimbabwe deserves some praise for its past efforts to create hydrometric networks and studies to assist water planning. Much effort was put into installing river gauging stations and rain gauge networks after the 1960's, although this network was heavily concentrated in the commercial farming areas. Zimbabwean hydrologists and meteorologists tried to use the latest techniques to study rainfall-runoff relationships to assist spatial predictions about water flows where flow gauging or rainfall gauging was difficult or non-existent (Kabell, 1962, 1972; Lineham, 1972; Mitchell, 1963, 1967, 1982). However, the database available for studying rainfall-runoff relationships in order to forecast and assess the possible effects of land use change was extremely limited. By 1998 the rainfall records in this sub-catchment were often fragmented and out-of-date. Raingauge coverage was biased to commercial areas, with the exception of gauges linked to some smallholder irrigation systems: large tracts of old communal territories still had no raingauge. There was a real need to re-design a hydrometric network that can be used to study rainfall and runoff patterns over the watershed in relation to different land use practices.

7.3 WATER LAW AND ITS IMPLICATIONS FOR HYDROLOGICAL ANALYSIS

The state of Zimbabwe/Rhodesia had separate Ministries for water resources, agriculture and rural development administration from as early as the 1950s (although names have changed, see Chidenga, 2003; Zawe 2000), and the fate of smallholder agriculture and irrigation has frequently been moved between agriculture and rural

development agencies. In fact, smallholder irrigation first became part of government action in the name of famine relief, under the Ministry of African Affairs (Zawe, 2000). Alongside these Ministries with development responsibilities, a Water Court eventually developed to deal with water rights issues. Almost from its inception the Ministry of Water and Natural Resources³ took responsibility for developing and monitoring networks of raingauges and rivergauging stations (hydrometric networks). The development of these networks start first in the older settlement and commercial farming areas. They began to develop more widely not only in relation to new scientific debates and norms for hydro-meteorological monitoring (Kohler and Linsley, 1970), but also in relation to how legislation slowly took more and more water sources into public control, out of private responsibility. While this growing public control indicated changes in cognitive norms on hydrology for development (which also echoed growing strength in government agency), technical norms of measurement and prioritisation have changed less.

Water law has evolved through a number of Acts and Regulations, and only the most significant are summarised here (drawing from Havilland, 1950; McIlwain, 1936; Natural Resources Board, 1984). The first European settlers, encouraged by the British South Africa Company (BSA Company), brought with them the Roman Dutch Law that had evolved in South Africa. From 1911 the white settlers agitated for independence from the BSA Company and this was finally granted in 1923. The Union Irrigation Act gave way in 1913 to the Water Ordinance and in 1920 further legislation was introduced. These ordinances established the lines of development for Zimbabwean catchments, notably through definitions of 'public' and 'private' streams, and the differentiation of types of use. The local promulgation of specific laws

³ This Ministry has moved through several changes of name. In this study the names of sections in 2000 are used: Department of Water Resources in the Ministry of Rural Resources and Water Development.

provided the basis for the establishment of a water court to support this settler agriculture.

A 'public stream' was originally described as a stream within banks, with a flow that can be applied to riparian lands. Other runoff – that might be captured by ephemeral runoff across a *vlei* (depression or wetland) for example – was considered private. Uses were differentiated into 'primary purposes' for human and farm livestock use and 'secondary purposes' for irrigation or the watering of stock other than farm stock. 'Tertiary purposes' included the needs of the mines and railways. The 1920 Water Ordinance stated that: 'if a farmer has land well suited for irrigation and there was a stream that could be economically utilised, he could acquire the right to use the whole of the water for irrigation even though it left others without water except for primary purposes'.

The ordinances of 1913 and 1920 set in motion a set of entitlements to take water for irrigation that would have profound later consequences. Of course, at this time the population of Rhodesia/Zimbabwe was barely 1 million and there was little visionary thought of what would happen as population grew and agriculture - especially as practised by smallholder 'native' farmers - changed and developed. Prior to the enactment of the new Water Act in 1998, there were three Water Acts that shaped water monitoring and planning in Zimbabwe, the Water Act of 1927, the Water Amendment Act (1947, 1948) and the Water Act of 1976. However, these never really transformed the way water allocation - and its hydrological analysis - took place. Rather, they refined and clarified procedures and brought in rules for allocation in dry years. These Acts actually tied in with important periods of settlement and changing political control, as well as changing pressures on the catchments. The changes in these laws have to be seen in this light, and there have been winners and losers in the process.

Under the 1927 Water Act, a Water Court and Water registrar was created that could issue and adjudicate on water rights. Also rights were identified as firmly attached to land. When land apportionment legislation created the Communal Areas (earlier Tribal Trust Lands), rights in these lands were registered with these bodies and not with individuals. Water rights could not be 'reserved for some indefinite use' in the future: they were to be within use within a specified period and failure to use rights for a similar period could lead to rights being revoked (McIlwain, 1936): three years was a first norm. There was provision for appointment of representatives for the 'native interests' in Irrigation Boards and in the Water Courts. Dams could be built without having to be registered if they were for 'primary use'. It also empowered appointment of officers for hydrographic surveys, if necessary to resolve water issues (McIlwain, 1936).

The Water Court fixed the conditions for which use of water was allowed. Application for a right for irrigation had to be publicized so that opposition could also be registered: provisional rights followed if there was no opposition or opposition was considered unfounded. Applicants had to specify the activity, and allowances for irrigation were fixed per acre per crop, for different times of the year. Before a permanent right was awarded, a permanent intake structure had to be built, and a certificate registered from an engineer that works had been carried out. Few individual smallholders using small water intakes entered into this process until after independence, however intakes for smallholder irrigation systems like Mutambara and Nyanyadzi did get registered through these processes, albeit sometimes later than their original actual startup date, and not without struggles.

The one provisional right revoked in 1997 from a private farmer along the Umvumvumu river was said to have happened because of irregularities found in the intake and use water as specified (personal communication, DWR representative).

Bolding (2004) documented several experiences in the Nyanyadzi river. For the oldest MuNyanyadzi furrow, the Water Court did insist on cement lining of the furrow and measurement of water losses during conveyance before granting a final water right in 1936. Despite an effort in 1936 to gain a water permit for at least 1000 acres for the big new Nyanyadzi smallholder irrigation system, the judge limited the amount and the territorial boundaries that this flow could serve. This did keep options open for European settler farmers in the upper part of the catchment, but was said to be done to ensure that water allocated did get used by African and settler farmers before any larger amount was allocated in the Native Reserves. Limited staffing for checks allowed both European and African farmers to abstract water quite informally. However, periods of low flows, or the incidental travel of officials in an area did bring 'illegal' irrigation to light quite often. This is shown in archived correspondence noted by Bolding (2004), who also described how, in 1947, Native Commissioners and representatives complained to the Water Court about illegal and wasteful irrigation by European settlers in the upper Umvumvumu that threatened downstream smallholder systems like Chakowa and Mutambara (although proper applications were then solicited from these farmers rather than foreclosed).

In 1948, there was also a protest against a new application from a European farmer on the Shinja river that might affect flows to the Nyanyadzi smallholder irrigation system, and there were further objections in 1951 through the Provincial Native Commissioner to the issuance of more rights to European settlers upstream of the smallholder irrigation project. A hydrological investigation was undertaken 1951-52 which exposed more illegal African furrows upstream also, and led to proposals for dams and better registration (Bolding, 2004). The problematic issue of how to allocate rights and set priority access such that irrigation development was possible in many years with higher flows, while limiting stresses in years of low flows, entered into the

domain of the government departments responsible for hydrological assessment and planning after the 1947 Act. This chapter returns to this dilemma and different approaches to assessment in sections 7.4 and 7.6

This 1927 Bill also clarified both acquisition procedures for water rights and also the priority right system to be applied during droughts, thus initiating rules that underpin many of the stresses found in the catchment in this study. Manzungu (1999) documents how the downstream Mutambara smallholder irrigation scheme tried legal action to the High Court in 1996 to stop abstraction upstream by a cooperative with a more recently granted right. However, the district administrator intervened to get the matter settled out of court, and it was still left to local irrigation staff to travel upstream and try and resolve the system unsuccessfully. Bolding (2004) also documented how the Nyanyadzi system had a 'lower priority' relative to the rights to water at low flows of farms with final rights registered before that of the scheme. Hydrologically, it gave a framework for better studies of water in the catchments, but still maintained the public/private dichotomy that kept some water sources outside hydrological study.

The Water Amendment Act 1947 (Havilland, 1950) brought this topic of the public/private dichotomy in water registration further under scrutiny. It noted that private water was 'that which naturally rises, falls or drains on to any land, provided such water is not naturally capable of entering any water course of natural origins'. This virtually confined private water to lakes, springs and vleis that did not have any effect, direct or indirect, on the flow of any stream. Proving this 'hydrological disconnection' was, of course, a negotiated rather than absolute outcome, dependent on hydrological understanding and legal relations in a point in time. The Act, in redefinition of allowances for primary use⁴, still left considerable powers for riparian

⁴ It defined primary use as that for human and animals, defining the limit as 50 gallons per person per day, regardless of colour or race that could be used in gardens for sewerage, or anything else.

landowners to take water without reference to other water users. Through its loose allowances for primary use – especially for ‘gardens’ and riparian users generally – it created scope for the development of unregistered small off-takes, the scale of which still remains unknown today. This might help explain the claims to rights by the many small water users who started to settle along the banks of streams after independence in 1980. Dams could be built without having to be registered if they were for ‘primary use’. Under a white settler government (and a lower population) priorities of rights were perhaps never in doubt, and were enforceable. As the government changed, however, so too did the potential for control of water abstraction.

While the 1947 Act tried to redefine private water in ways that might open more water sources to hydrological scrutiny, it also defined a zone that began to stay outside public study and management. These were the *vleis* (*dambos* or wetlands in depressions), springs and streams beyond public streams that were being used by both smallholder farmers and commercial farmers. It may have helped to fuel the further use of *vleis*, intermittent flows and lakes. This might also help to account for the declining base flow and peak flow of rivers. Finally, the Act recognised new uses in the catchment such as fish farms and conservation activities that were the result of new commercial interests.

According to the Natural Resources Board (1984), the 1976 Water Act was seen as an ‘amending Act’. It contained provisions that made it possible for the Minister to reserve water for future use and declare water control areas in regions where the limits of exploitation had been reached. It also required the better registration and technical survey of new dams to ensure dam safety. During the 1950’s both irrigation and dam technology had become more sophisticated and much information and experience had come from the USA. The Act allowed for outline plans to be prepared for the development and use of surface water and for public involvement in planning purposes.

The 1976 Water Act also clarified and created regulations for permits for groundwater use for the first time – by this time settlement schemes were being planned based around development of borewells. The Act also brought in some hydrological definitions to help planning. It introduced the idea of ‘normal flow’ as the criteria for planning purposes. This was ‘public water’ not directly occasioned or caused by floods due to rainfall. By the early 1960’s, hydrologists had started to investigate base flow patterns and rainfall-runoff relations in the major Rhodesian/Zimbabwean rivers (Kabell, 1962, 1972), but such analysis was never brought down to local river level (see section 7.4). The 1976 Act also provided for some stakeholder participation in such institutions as the River Boards (but which were never really established widely). This was a reaction to water management realities on the ground, where local arrangements were needed to deal with water scarcity. However, participation was restricted to water right holders. Then the Unilateral Declaration of Independence (UDI) and ensuing liberation war stopped further hydrological refinement, modeling and local planning development until the 1980’s.

The 1998 Water Act (Chapter 20:24) made sweeping changes in the institutions of administration and law. Water was no longer private property, and access to water was to be given through a permit system. Catchment councils were created with responsibilities for monitoring, the issuing of permits and the production and monitoring of plans. They could also appoint sub-catchment councils to help with all activities except the issuing of permits. The ‘priority right’ allocation procedure for low flows was terminated, leaving responsibility with the Catchment Councils to propose controls as they saw fit during periods of low flow. They were also empowered to declare water shortage areas, if dams and stream flows dropped below minimum level, and able to reduce permit allowances where considered necessary. A new National Water Authority (ZINWA) was created to develop water management plans and

oversee apportionments between different sectors and public/private users, manage hydrological stations, and ensure the Catchment Councils and local authorities discharged their duties as far as water planning and potable water provision and disposal were concerned. The powers and responsibilities of ZINWA were defined in the accompanying Zimbabwe National Water Authority Act (Chapter 20:25). However, the Minister also held powers that made it possible for him or her to intervene and change the decisions taken by both the ZINWA and the Catchment Councils. Issues related to water supply in the Communal Lands were mentioned specifically, and the appropriate Minister had the right to nominate an appropriate person to represent these interests (as discussed later, the Save Council included a communal leader from Mutambara Communal Lands).

In terms of hydrological planning, the 1998 Water Act gave new recognition to hydrological issues. It encouraged localised, catchment-focused planning and management with stakeholder representation, promoted integrated water resources management, introduced pollution monitoring, and introduced a requirement to meet the needs of aquatic and associated ecosystems. Finally it gave a stronger definition of a 'public stream' - "a watercourse of natural origin whether or not it is dry during part of the year or changed by artificial means" - which was to come under a Catchment Council.

The DWR also continued to monitor and compile hydrometric data but how analytical work would be funded remained unclear. There was no strong commitment to improving hydrometric networks in the Act, and the acquisition of resources to do new monitoring and data compilation was left largely undefined. During this research, external donors did start to assist different catchment councils in their new monitoring work. However, no changes emerged in the Save catchment, where interviews also suggested that most available funds went on salaries and attendance allowances. Also

the issue of water use in gardens was not specifically referred to and the right to use water from 'private streams' remained vague. Small dams could still be built without a permit. The new Act of 1998 gave a stronger integrated focus to water management and ecology issues. It specified (Water Act, Chapter 20:24. Part iv section 67) that due consideration should be given to the protection, conservation and sustenance of the environment. While fresh attention to water quality and aquatic ecosystems was welcome, it introduced potential new stresses into the water allocation debate.

7.4 WATER AVAILABILITY OR WATER SCARCITY? TECHNICAL NORMS AT WORK

The way that water availability is described is influenced by the way it is seen to provide benefits and challenges to society, and how planners think they can control and develop it. Sections 7.1-7.3 have shown the emergence of several norms shaping agricultural and water planning:

- the definition of Natural Regions in agricultural planning, in which rainfall and its seasonality was a critical element;
- the concept of the 'public stream' and its 'normal flow' on which water rights could be allocated. In Zimbabwe, water availability was primarily studied in terms of potential dam yield if this flow was regulated, and the safe yield from such dams (based on flows exceeded – i.e. available - 90% of the time, or a 10% failure level).

Planning studies also estimated the present level of dam regulation and yield and the 'potential' remaining if more dams were built. Flow yield was classified as three kinds: Type A was the base flow of a river available throughout the year. Type B was yield from rivers at a selected risk factor, in this case with draw off equivalent to annual runoff exceeded 90% time, from small dams with annual storage. Type C yield was the

maximum yield that could be obtained from dams with overyear storage, with a 10% risk of failure (Ministry of Water Resources and Development, 1985. (For details see footnotes to Table 7.2).

- a system of definition of primary use, related with priority dates in water right acquisition, that determined who got water at times of low flow;
- a growing interest in dams as a crucial technology to store water against seasonal droughts;
- a planning framework where central monitoring and consolidation of data that stopped at the hydrological unit or sub-hydrological zone level. In fact it was these major tributaries that were first the target of government efforts at major dams for regulation. Potential smaller dam sites were identified on the Nyanyadzi and Umvumvumvu rivers but never developed.

These norms all helped to shape the evolution and reinforce use of another critical technical norm that became applied to all rivers subjected to flow gauging - the **mean annual runoff**⁵ (MAR) expressed as a depth in millimetres. This parameter was seen as the most useful to represent the available water supply for development. The 'scientific' approach was that MAR could be compared with rainfall for water balance studies, and also be related to increased potential runoff from an area after flow was captured by dam construction.

This section investigates the different understanding of problems that emerged when this parameter was applied to local streams, to see the stresses 'looking up from the field' – as opposed to understanding when it was just averaged for the Odzi zone - as central planners of the time did. By 1985, a set of calculations were in place that gave

⁵ Mean annual runoff expressed as a depth gives a parameter that can be compared with other climatic data expressed as a depth, such as rainfall and evapotranspiration. Typically it is calculated from runoff formulae which may include coefficients for relief, landuse etc. Estimation of runoff from rainfall has been a common practice where runoff records are inadequate for further study.

indications of what levels of yield could be supplied from dams, either from annual storage or overyear storage. However, while these 'regionalised' water parameters could help in planning allocation and development in relation to total annual flow, they could not help in assessment of allocation of actual flows, which are studied further in section 7.6.

Table 7.2 first shows average mean annual runoff of 110mm for the watershed. This expresses long-term average river discharge as a depth over the catchment drained by the river (some older reports gave this as 102 mm). This of course is much less than the average rainfall and reflects losses through evapotranspiration and seepage. As Water Resource Planning publications (Kabell, 1972) noted, this figure 'is primarily dependent on rainfall...to a lesser extent it is dependent on catchment characteristics such as soil type, vegetation and cover, land use and topographical features'. The planning figure was in fact largely estimated from rainfall. This table begins to show what could be available for use in an 'average year'- if all water were captured and stored: calculation procedures for yields possible with different levels of storage and risk are shown in footnotes with the table.

Table 7.2 shows the Lower Odzi watershed as one where the reliable flow from potential dams sites is under-exploited, although the resultant safe yield from all possible storage is still very much less than mean annual runoff. This low 'safe yield' potential of only 58 mm reflects the dry climate and problems in regulating rivers with such extreme flows. The calculation of yields from different levels of dam storage were all done for a 10% risk, i.e. that a failure of 1 year in 10 was a practical level for farmers of that time.

In fact, by 1985 there were discussions of whether this risk could be raised to 20% once there was adequate potential for storage. By this time, more was understood about the water stresses that plants could withstand. Kabell wrote (in Ministry of Water

Resources and Development, 1985) that farmers growing annual crops could adapt their farm plans to known levels of water storage. Farmers growing perennials could also estimate what levels of yield reduction could be withstood by lower levels of water application. In this context, the 1927 Water Act had allowed the formation of 'combined irrigation systems' and Water Boards, shareholders in which would have water rights alongside responsibilities in payments of water rates and development capital (McIlwain, 1936). Such combined schemes to supply private commercial farmers did gain rights in the Lower Odzi (for example the Penkridge scheme along the Umvumvumvu) and elsewhere (Zaag and Roling, 1996, document the problems and actions of farmers in the Nyachowa system). Where they were linked with dam construction, shareholder farmers might even trade or defer rights in relation to offakes in a dry year. However, in unregulated rivers the priority rights rule was the only principle by which to allocate water rights in low flow years. Initial attempts to give smallholder farmers individual titles failed, and representation of their rights to water could only be claimed via the Native Commissioners (see Bolding, 2004).

However, in 2000 the Umvumvumvu river still had no dams regulating the river overall, although some farms rights for small water storage. It was thus still largely what was characterized as a Type A river, where reliable base flow was still seen as the main guide to allocation. As section 7.5 shows, serious action to control rights and revoke the burgeoning number of licences really began in the 1980s as a new order began after independence. Most of the revoked licences were along the Nyanyadzi and Odzi rivers. However, while only one licence was revoked along the Umvumvumvu, the problems faced in the smallholder irrigation systems there also showed that allocation was probably going above reliable base flow levels.

The Chakowa smallholder irrigation system (90 ha), located in the downstream zone of the Umvumvumvu quite close to its confluence with the Odzi, had its first block

developed in 1934 with a water right of 60l/s: this was later increased to enable four further blocks to be developed, with a right of 112 l/s when water was available. In 1970, despite construction of night storage reservoirs, plans for the last of these blocks were shelved as water supply was inadequate (Chidenga, 2003). Water stress was visible also in the current scheme, where tail end blocks grew less water demanding crops and had poorer irrigation frequencies and performance (see Chidenga, 2003). Manzungu (1999) documented the problems in Mutambara smallholder irrigation system upstream of Chakowa, also to get adequate water for all its farmers: Mutambara also had a two level water right depending on the flow available. Thus, for this study, two levels of development were considered, to represent what might be a representative level of allocation for low flows without serious conflicts. The first was the MAR level of 4.2mm, the consumptive use level monitored in 1970 (see Kabell, 1970). The second was the consumptive use level of 5.0mm measured against 'available storage' of 0.4mm in 1983, by which time the problems of Chakowa suggested allocation was already beyond what was feasible in years of low flow given actual storage levels. No full grants for water rights involving storage were issued between 1985 and 1998 (Water rights register). By 1998, allocation had increased to the equivalent of 5.3 mm. A figure of 4.2 mm is thus used in table 7.7 to represent allocable base flow with minimal storage (less than 0.5mm).

From figures, it looks as if the Lower Odzi watershed has an 'underdeveloped' status, where there was quite some room for manoeuvre even if there were a few problems. However, when looking into detailed records and problems along rivers, indications are clear of the actual pressure arising from the levels of water right allocation in the face of a high variability of flow. Fig 7.1 shows the river systems of the Lower Odzi watershed now discussed in more detail.

Table 7.2. Lower Odzi Watershed, Mean Annual Runoff and Yield, from planning publications (Ministry of Water Resources 1985) and Water Rights Register

LOWER ODZI WATERSHED KM ²	MEAN ANNUAL RUNOFF ⁽ⁱ⁾ (mm)	YIELD (mm)	
2426	110	With annual storage ⁽ⁱⁱ⁾	17.61
		With over-year storage ⁽ⁱⁱⁱ⁾	69.34
		10% 'safe yield' with over-year storage ^(iv)	58.00
		<u>Level of utilisation</u>	
		1970 ^(v)	4.2
		1983 ^(vi) (0.4mm in storage)	5.0
		1998 ^(vii) (0.5 mm granted for storage)	5.3

Derivation of figures (Source: Kabell, 1972; Ministry of Water Resources and Development, 1985; Mitchell, 1963; Water Rights Register).

i) The Mean Annual Runoff (MAR). This is long-term average runoff, seen to represent the total input to surface water potential. It is estimated from precipitation measurements (amount, intensity and distribution), with coefficients also for soil type, vegetation and cover, land use and topographical data.

River Flow: Potential yields of rivers were originally classified as of three kinds:

Type A: Yield was expressed as the base flow of the river available throughout the year and every year. Estimates were derived in relation to the baseflow of annual hydrograph drawn for (low) flows received in 10% years (i.e. exceeded 90% of the time). Even in 1985 it was noted that... 'the volume of water in this classification is small and in most catchments in Zimbabwe it is already utilised' (Ministry of Water Resources and Development (1985) ..p.1

(ii) Annual storage was derived as a Type B yield. This was the 'potential annual yield' possible from storage that balanced varied monthly flows, where dams were thus also quite small. Yield was estimated as 80% of an estimated storage capacity (this allowed for losses from evaporation). This storage capacity was calculated from a graphical relation, that related the total annual runoff with 10% chance of occurrence (estimated from the Gamma distribution) and Coefficient of Variation (CV). For the Lower Odzi the CV was 80%, thus storage capacity was 0.2 of the MAR of 100mm, or 22mm. Potential yield with annual storage was 80% of this 22mm, to allow for losses i.e. 17.6 mm.

(iii) Overyear storage was derived as a Type C yield. This was the 'potential catchment yield' - that which could be obtained at a given risk factor over an indefinite span of years, using reservoirs that have overyear storage, that balanced out variability of flows between years as well as across a year. As it was dependent on larger structures, there was greater loss from evaporation and water is more expensive. In analyses, storage capacity was expressed as a ratio of MAR. While twice the MAR was a working norm as a general practical limit, actual estimates were also related to the CV of annual runoff. For the Lower Odzi, the optimal storage potential in 000m³ was taken as 1.3 MAR (expressed a volume). The CV was 80%, and the ratio of MAR taken for estimating 'potential catchment yield' was 0.63, giving a figure 0.63 (110) or 69.3 mm.

(iv) This potential yield with overyear storage was further adjusted to build in a safety factor that allowed for risk of failure. The risk levels taken were 10% for agricultural uses, and 4% for urban use, thus planning estimates also cited respectively 90% of potential yield (yield at 10% risk with overyear storage) and 96% of potential yield (yield at 4% risk with overyear storage). These different general yields were estimated for larger dams for the subzone, by a procedure known as a Transitional Probability Matrix (TPM) that integrated likely reservoir characteristics (relationship of capacity and surface area that would affect losses), draw-off patterns and further statistical analysis. The figures cited here for yield from overyear storage at 10% risk were taken from Ministry of Water Resources and Development, 1985. Information on the TPM procedure is given in Mitchell (1967).

(v) Calculated from Water Rights Register: storage level is not assessed because of difficulties in knowing when and if some rights were increased from original oldest rights

(vi) from Ministry of Water Resources and Development (1985)

(vii) sum of all applications for rights summed from the Water Rights Register.

Tables 7.3 -7.6 show the mean annual runoff and the actual range of runoff for the various river systems within the Lower Odzi watershed as calculated in this study. This gives quite a different picture. The main river systems show a much lower mean annual runoff than the overall sub-catchment average of 110 mm, especially in their lower reaches, and the wide range of flows annually is immediately apparent. While this can be due to different rainfall-runoff characteristics especially in the drier hotter communal areas, it will also reflect the level of abstraction along these streams. Finally Table 7.7 shows the current level of water rights allocated, expressed as mm depth. These rights appear to be only a fraction of the mean annual runoff – yet they are already above the lower range of mean annual runoff. This indicates the high level of flow variation against which rights must be allocated. Thus a legal rights structure must be present that really can manage prioritisation or reallocation of water at low flows.

Tables 7.3-7.6 also show that most rivers experienced a decline in average annual runoff along their course. The data in these tables is from computerized monthly records with the DWR: figures in brackets give runs of years used. In some rivers, upper tributaries/gauging stations have much higher rainfall, and often very high peak flows. They may maintain the same or greater base flow across the year than lower reaches of the same river, indicating the importance of these upper reaches in supplying base flow for downstream needs. These phenomena are also very important for planning the spatial allocation of water rights.

Table 7.3. Mean Annual Runoff and Range Of Runoff, Lower Odzi, expressed from monthly flow data (years of gauging records used given in brackets)

ODZI RIVER SYSTEM	MEAN ANNUAL RUNOFF (mm)	RANGE OF MAR (mm)
Odzi–Maranke gauge (1961/62-1999/2000) (upstream of Lower Odzi catchment boundary)	113.7	5.9 –336.2
Odzi Hot Springs gauge (1949-1974/75)	94.8	5.4 – 260
Odzi Gorge gauge (1983/84-1999/2000) (downstream gauge before confluence with the Save)	77.2	1.0 – 402

In the main Odzi river, the wet season flow measured upstream of this watershed at Maranke Weir was 60-75% of the outflow from the watershed measured at Odzi Gorge, showing contributions from in-flowing tributaries. However, in the dry season, the flow measured upstream was twice as high as that measured at the outflow (Odzi Gorge) (Smits, 2001). This indicates both a limited contribution from any tributary streams and the effect of water abstraction, seepage and evaporation losses. These seasonal and spatial differences may also be affected by the policies for release from the Osborne dam. No new permanent water rights had been granted in this stretch of the Odzi since 1991.

Table 7.4 Northern Tributaries, Mean Annual Runoff and Range Of Runoff, derived from monthly flow data (years of gauging records used given in brackets)

NORTHERN TRIBUTARIES	MEAN ANNUAL RUNOFF (mm)	RANGE OF MAR (mm)
Whitewaters gauge (1968/69-1997/98)	22.2	0 – 58
Wengezi gauge (1982/83-1996/97)	303.8	10.8 – 1300

The upper rivers gauged in this hydrological unit show highly variable flows, with the intermittent Whitewaters stream well below the mean annual runoff of the whole watershed. The larger Wengesi river has a higher mean annual runoff with its higher flood flows shaped by rainfall over the eastern mountains.

Table 7.5. Umvumvumvu River, Mean Annual Runoff and Range Of Runoff, derived from monthly flow data (years of gauging records used given in brackets)

UMVUMVUMVU RIVER SYSTEM	MEAN ANNUAL RUNOFF (mm)	RANGE OF MAR (mm)
Umvumvumvu Cashel gauge 125 (1970/1971 – 1997/98)	116.6	1.9 – 261
Tandai gauge (1956/57-1997/98)	128.8	3.3 – 335.3

Table 7.6 shows that the mean annual runoff depth in the Tandai catchment, an upper tributary, was substantially higher than the average for the whole Umvumvumvu system, with its lower rainfall zone downstream. In the Umvumvumvu system, the

upstream flow in the Umvumvumvu at the upper 'Ostend' gauge near the Tandai river was some 40% of flows received by the downstream gauge in the wet season (Smits, 2001). This indicated an inflow from other downstream tributaries like the Ruwaka and Nyambewa as well as flows triggered by rainfall along the river zone itself. However, in the dry season this upper river flow gauge showed similar or greater flow than the downstream gauge at Cashel Road bridge. This also indicated that there was little contribution then from other tributaries in the dry season, and even a reduction due to abstraction (such as by the Mutambara irrigation system) or losses from seepage and evaporation. The Tandai tributary of the Umvumvumvu was, on average, equivalent to some 18% of flows in the wet season and 40% in the dry season of flows measured at the 'downstream' Cashel Road Bridge Gauge (Smits, 2001). Thus any re-development of water allocation on the Tandai needs serious consideration because of its significance to dry-season flow given downstream commitments. The Tandai river and the McAndrews – Ostend zone of the Umvumvumvu river, both of which maintain base flow in most years, were the first main zones of European settlement. The gauges monitoring these flows were also the oldest in the whole Lower Odzi sub-catchment (operating since 1956): this shows the economic priorities in the original development of the gauging network.

In the Nyanyadzi system, water stresses were especially apparent. Table 7.6 indicates that several rivers showed runoff well below the potential MAR, and that the runoff equivalents decreased between upstream and downstream gauges, probably reflecting the larger drier areas in the lower catchment, as well as abstractions along the river. These relationships need further study. However, the flow gauges of some tributaries were no longer operating and had gaps in their records, so flows were not averaged over similar time periods.

Table 7.6. Nyanyadzi River, Mean Annual Runoff And Range Of Runoff, derived from monthly flow data (years of gauging records used given in brackets)

NYANYADZI RIVER SYSTEM	MEAN ANNUAL RUNOFF (mm)	RANGE OF MAR (mm)
Nyanyadzi gauge 121 (1968/69-1995/96) (upstream of main tributaries)	93	2.5 – 234
Nyanyadzi gauge 119 (1968/69- 1997/98) (downstream of major tributaries, upstream of Nyanyadzi irrigation scheme)	90.5	2.8 – 508.9
Moosgwe gauge (1955/56 – 1997-98)	13.8	0.3 – 144.9
Shinja gauge (1970/71-1999/2000)	43.9	2.6 – 124
Mhakwe gauge (1969/70 -1976 /77)	124.9	19.6 – 226.5
Biriwiri gauge (1968/69 – 1997/98)	113.3	2.4 – 614

Tributary streams like the Moosgwe and Shinja were strongly below the mean annual runoff of the Lower Odzi watershed. This was partly due to lower rainfall and their more ephemeral nature, but also to their development: Table 7.8 reflects these struggles through the numbers of rights revoked in the area. (The Shinja communal area covers the Shinja stream and also abuts onto the Nyanyadzi river). In the Nyanyadzi river system, flows in the Biriwiri tributary (also a zone of early settlement) are some 30-40% on average of the lowest gauge in the Nyanyadzi river. Any major new developments in the Biriwiri river will, therefore, also have implications for downstream flows of the Nyanyadzi and the security of water access there.

The contested Shinja river contributed flows of about 10-20% to the downstream flow, peaking at 30% in November around the early part of the rainy season. This local significance of the Shinja flows explained some of the conflicts documented by Bolding (1997, 2004) where officials and irrigators from the Nyanyadzi irrigation system traveled upstream to destroy offtakes upstream on the Nyanyadzi and Shinja rivers.

Finally, Table 7.8 gives an estimate of the current water right situation, also expressed as a water depth. So far, the water allocation in rights appears low – only around 5 mm or approximately 5 % of mean annual runoff.

Table 7.7 Allocated water rights in the Lower Odzi Watershed, expressed as mm depth by 1998

Water rights, Lower Odzi Watershed, 1998	- 5.3
Mean annual runoff, Lower Odzi Watershed	- 110.0
- 10% safe yield with over-year storage	- 58.0
- Estimated allocable baseflow with available storage (less than 0.5 mm)	- 4.2

However, stress was already present at such a development level, as the water rights issued for the watershed were still more than the estimated allocable baseflow expressed as MAR with available registered storage. In fact, these water right figures are probably an under-estimate of use because of illegal abstraction and the problems of revoking provisional water rights in reality. Nevertheless, the figure serves to show the dilemmas in the watershed. The table shows what might be possible with more dams: however it is unlikely that finance be available for their construction in the near future.

The MAR parameter was a strongly embedded technical norm in water planning in Zimbabwe: its use was strongly related with a wider interest in dam design development found both in government agencies but also with commercial farmers. The parameter was relevant for showing some of the inherent variability and levels of scarcity found in small tributary streams. However, it had not been applied before to show either this variability in flow across years, or the spatial conditions of variability along smaller tributary streams. The structure of institutional responsibilities in water administration had kept its application to larger catchment areas and to its use as an average figure, consistent also with a water development policy strongly focused into dam construction. The next two sections look further into the history of watershed development, and the struggles for smallholder irrigators with this variability and uncertainty.

7.5 WATER RIGHTS AND KEY ACTORS IN THE WATERSHED

The water rights in the Lower Odzi have been strongly shaped by white settlement in the upper catchment streams, as well as by rights allocated for smallholder irrigation to communal lands for both irrigation schemes and individual use. Commercial tourism development along the Odzi also played a role. Table 7.8 shows this growth over time. In the Umvumvumvu system, settlement began in 1917, but key periods of expansion were 1930-1940, and 1945-1955. Registration since 1975 was very limited, and in fact many white settlers left their farms during the liberation war. Some new smallholder cooperatives had registered for rights, but there was also unregistered use in the form of small furrows. There were no new registrations since 1989. Along the Nyanyadzi river, there were fewer commercial settlers and most of them came in the period 1950-55. Since 1981 there were many more requests for small water rights in the old communal areas.

In the past, water rights were first granted as a right to extract a flow. It was possible for an abstraction right to be limited to a period, or periods when river flow was greater than a certain level. It was also possible for a farm to hold a right for use throughout a year and an additional right for a certain period, such as during the dry season. These 'double rights' were found on some Umvumvumvu commercial farms. Group rights were also given to irrigation companies and cooperatives as well as to smallholder irrigation systems registered under the communal authority. A critical issue in 2000 was whether and how individual rights and responsibilities would be given to individuals. As explained earlier, water rights were granted first as provisional rights. The grant was confirmed once the necessary and required headwork development has been done, and if there were no complaints.

Table 7.8 Date of water rights issued, Lower Odzi watershed

Figures show total volume of rights per year in 000m³. The numbers of rights issued is given in brackets (rights pending not included)⁶

PERIOD	UMVUMVUMVU RIVER SYSTEM	NYANYADZI RIVER SYSTEM	WENGEZI, MURARE & WHITEWATERS RIVERS	ODZI RIVER
1916-19	616.7 (1)	-	-	-
1920-29	424.3 (4)	-	-	-
1930-39	2592.5 (12)	1062 (4)*	-	-
1940-49	1536.3 (28)	242 (2)	258.7 (7)	-
1950-59	1480.1 (12)	312.3 (11)	132.5 (5)	2427.9 (5)*
1960-69	460.8 (18)	205 (6)	241 (4)	98.7 (1)
1970-79	176.4 (5)	66 (3)	-	-
1980-89	73.5 (4)	783 (43)	6 (1)	19.3 (2)
		REVOKED 240 (18)		REVOKED 19.3 (2)
1990-98	- REVOKED 152.4 (1)	192 (7) REVOKED 192 (7)	-	108 (2)
TOTAL NET	7206.2	2430.3	638.2	2634.6

* for the Nyanyadzi irrigation system, the current rights list a surface abstraction from the Nyanyadzi river and a lift abstraction from the Odzi river which together are still too small for the current irrigated area. However, the stress in the scheme for surface supplies is created when pumps are not used because of breakdowns and operational preferences

During the 1990's a number of provisional rights were revoked, notably in the Nyanyadzi catchment, but also along the Odzi. During the late 1980's, the irrigation system manager and irrigators from Nyanyadzi traveled upstream at times of low flow and burned any gardens irrigated from illegal 'informal' furrows. A lot of applications for water rights were then applied for, but these were not supported and many,

⁶ The data compiled was taken from a record list of 1998, when rights were still being requested and issued and totals both permanent and provisional rights listed. It compiles the volumes allowed for abstraction per year, for both a full right and those operating only part of the year. Several entries had to be checked for compilation errors where flows and volumes listed were not consistent. The dates used relate to the first date of issue of rights, even though some rights have been broken up and reassigned, for example with the Penkridge rights: reassigned rights are not re-entered into the total. Thus the figures in this tables should be treated as approximate, but rounding up was not done to avoid over-exaggeration of allocation.

therefore, remained provisional or were revoked. This explains the high level of revoked rights visible in Table 7.8.

There is a significant difference in types of right seen. The communal lands show both large allowances for communal smallholder irrigation schemes, but also flows based on units of 1 l/sec to irrigate one hectare (Water Rights Register). These 'communal area' rights accounted for many of the rights issued for the communal lands crossing the Nyanyadzi river system. These rights are visible from the 1950's and are especially evident after 1980. They probably represent rights allowed to individual farmers after the Native Land Husbandry Act, and later the resettlement of lands after independence in 1980. Since 1990, provisional rights have been increasingly requested on small tributary streams - where perhaps 'riparian rights' are easier to assert because there are relatively few other riparians close by to protest. On smaller watercourses with temporary flow it may also be possible to claim the land as a *vlei*.

The amount of water requested within these 'communal area' rights has also started to increase. In 2000, several provisional rights were registered for rights of 60 l/s 'for stock watering' along tributary streams of the Nyanyadzi - although this flow is the same as supplied to small-scale irrigation systems of some 90 hectares.

Among commercial farms and other non-communal users there was been a range of size of water allowances - large and small. Typically, in the upper Umvumvumu and Nyanyadzi rivers, individual farm estates held several rights - at different places and even over different streams. The effect of this 'spatial hold' over streams and the water resources in the upper area needs further study.

In the Umvumvumu, there were some small dams linked to individual farms and an old Irrigation Board on the upper streams, but no regulation of the main Umvumvumu river. Although there were over 90 rights allocated, many actors had more than one right in their property, whether commercial enterprises or communal lands. Most rights

granted were 'full grants' – only one provisional licence was revoked in this catchment - from a non-communal owner. Maps showing the location of intakes suggest, however, that there were other sites, where rights were once considered.

The Nyanyadzi river had less water allocated in rights than the Umvumvumvu, but had a greater struggle for water. There were regular scarcity problems where downstream users took action to stop 'illegal' use upstream of the Nyanyadzi irrigation system. In addition, its seasonal flow and water level meant that access was much more contested. In the Nyanyadzi river, over 70 water rights were allocated – with smallholder rights in different communal lands and wards. During the 1990's around 20% of water rights granted provisionally were revoked, notably along the Shinja and Mhakwe rivers. All the revoked licenses were within communal lands and wards. No private licenses were ever revoked. Table 7.9 now tries to show the balance between these actors.

The Umvumvumvu was the river with the greatest number and volume of rights granted, followed by the Nyanyadzi. But there were also major questions of power embedded in the access shown. This power balance was not simply an issue between commercial farmers and smallholder irrigators, although this is clear from the table and a vital issue. As can be seen, organized private or cooperative enterprises took 55 % of the water overall, and 74% of water in the Umvumvumvu river.

Table 7.9 Water rights allocated to different classes of rightholder in the Lower Odzi Watershed by 1998 (M³ are 000m³) (Source: Water Rights Register, Harare)

Rightholder type/ Registration point	Umvumvumu river	Nyanyadzi river	Odzi river	Wengesi Murare & Whitewaters	% of total volume of rights in Lower Odzi watershed
Private farms, coops and other non-communal holders*	76 rights excluding 1 revoked 5317.3 M ³ (74%)	21 rights 887.2 M ³ (36.5%)	3 rights excluding 2 revoked 306.6 M ³ (11.6 %)	16 rights 632.2 (99%)	55.3
(inc roads)*	4 rights	5 rights		2 rights	
Mutambara Communal Land	8 rights 1889.1 M ³ (26%)	6 rights excluding one revoked 99.0 M ³ (4.1%)	1 right 72.0 M ³ (2.7%)	-	16
Nyanyadzi Communal Land		1 right excluding one revoked	-	-	0
Muwushi Communal Land		23 rights excluding 9 revoked 1348.1 M ³ (55.5%)	1 right 2220 M ³ (84%)	-	27.6
Muromo Communal Land			1 right 36 M ³ (1.4%)	1 right 6 M ³ (1%)	0.3
Shinja Resettlement and wards		19 rights excluding 11 revoked 96 M ³ (4.0%)	-	-	0.7
Chimanimani		1 right excluding 1 revoked			0
TOTAL	7206.2 M ³	2430.3 M ³	2634.6 M ³	638.2 M ³	12909.5 M ³
% TOTAL ALLOCATION IN LOWER ODZI	55.8%	18.8%	20.4%	4.9%	

*small rights are allowed for use for road building/repairs
Revoked' indicates the cancellation of a provisional right.

Power was also an issue in the relationship between different users in the communal lands and their representatives. This chapter has already shown the stresses downstream in the Umvumvumvu, especially between the smallholder irrigation systems of Chakowa and Mutambara to get their water. Yet both systems were registered under the same communal land, which also has registered water rights further upstream. All fell under the adjudication of the local communal representative – in 2002 the Chief of Mutambara. There put real stresses on such local representatives, like the Chief of Mutambara, who had different interests in different schemes across the catchment: those of the Mutambara scheme versus others like Chakowa downstream. In the Nyanyadzi, local councils and groups with people from five communal areas also had different interests as stakeholders in the struggle for water along the river system.

Thus the table also shows how the ‘power broker’ for the communal lands was Mutambara, holding rights on the Umvumvumvu and Nyanyadzi rivers, the two most important tributaries in the Lower Odzi watershed. Along the Nyanyadzi river, although the Muwushi Communal Lands held more water in registered rights than Mutambara, it had also seen many of its rights revoked as smallholders have tried to register small rights. The Chief of Mutambara was the representative for the communal areas on the sub-catchment council in 2000. Table 7.9 helps to show why there had been such struggles between some smallholder users - along the Nyanyadzi river (fuelled by the spatial geography of those holding rights), and between Mutambara irrigation system and other rightholders along the Umvumvumvu.

This section ends with an overview of the range in size of water rights registered in September 2001 (at this time still awaiting conversion to permits), shown in Table 7.10.

Table 7. 10 Range of size of agricultural water right in operation November 2000**UMVUMVUMVU RIVER SYSTEM**

SIZE OF RIGHT(L/S)	COMMUNAL AREAS		PRIVATE		TOTAL	
	Granted (revoked)	Provisional	Granted (revoked)	Provisional	Granted	Net
<1	2		12		14	
1-1.9	3		9		12	
2-4.9	1	1	25	1	28	
5-9.9			13		13	
10-19.9			10 (1)		10	
20-39.9			6		6	
40-79.9	1		1		2	
>80	1		1		2	
					91	90

NYANYADZI SYSTEM

SIZE OF RIGHT(L/S)	COMMUNAL AREA		PRIVATE		TOTAL	
	Issued (revoked)	Provisional	Granted (revoked)	Provisional	Gross	Net
<1	17 (2)		2		19	17
1-1.9	23 (21)		1		24	3
2-4.9	14 (1)	4	7		25	24
5-9.9	-		8		8	8
10-19.9	1(1)	1	1		3	1
20-39.9	-					
40-79.9	-	4		3	7	7
>80	1					1
					88	63

In the Nyanyadzi system some 58 % of rights (including those revoked) were for less than 2 litres/second, a very low flow for which to create a headworks and measure. In both rivers systems, there were both private and communal offtakes with rights of over 50 l/s, but the majority of water rights in communal lands were under 5 l/s. The current Act gives greater powers to request the measurement of water abstractions, but this will be challenging for the small flow rights granted in this watershed. Unregulated rivers like the Umvumvumu and Nyanyadzi are more prone to floods and these can damage offtakes and make sustained offtake management difficult: cyclone Eline in 2002 washed out many small registered intakes. Government priority will always go to

larger works after such emergencies. Commercial farmers have tended to be upstream in the catchment in higher rainfall areas where they face fewer extreme events, and also have access to more labour to rebuild any offtakes that may be washed away.

This section showed how study of the historical evolution of rights, and also the spatial spread of users, demonstrated many of the emergent pressures on local water management. It shows what further information on water scarcity can be elicited when hydrological research studies the nature of rights and users in the field and on a map, and not just calculates the quantity of water allocated inside a computer.

7.6 UNDERSTANDING THE COMPETITION FOR WATER

What then are the actual risks for smallholders along the different 'local' tributaries of the Lower Odzi watershed? This section tries to answer this question, through the use of very common hydrological techniques, that were also not formerly applied in Zimbabwe given the other technical norms in use. It proved quite difficult to collate and cross-check flow gauging stations, especially for the Nyanyadzi system, because data records were fractured by the liberation war. However, a study from the Cashel gauging station on the Umvumvumu is now used to show the stress in the catchment and the need to develop more sensitivity to the local problems for smallholders.

At Cashel, the main downstream water rights lie with the Mutambara Communal Lands and there is only one other 'non-communal' user. Mutambara rights include the Chakowa irrigation system (a right that dates from 1935), a private right at Mhandharume as well as a few smaller rights registered to Mutambara that will irrigate 1-3 three hectares. Chakowa had a right to take up to 112 l/s when water was available, but otherwise 60l/s. These equated with a total downstream demand of about 120 l/s. However, the Chakowa system had not registered an intake above 64 l/s since the end

of the 1980's⁷. A key practical problem was also that such low flows in a wide river bed creates difficulties for an irrigation intake as low flows pool, meander, and move within the river bed, and so require training and sandbagging to obtain water. In fact to allow for channel seepage and losses and informal extraction, a flow of 200 l/s at the Cashel gauge might be better to guarantee downstream flow at Chakowa.

The Water Act of 1998 specified that due attention should be given to the protection, conservation and sustenance of the environment. HR Wallingford/DFID (2003) gave a review of methods that could be used to estimate allowances for environmental water demand and use, that could also be expressed as a minimum flow requirement. The one most consistent with available data was the aquatic base flow method. This is based on the assumption that the median flow for the lowest flow month is adequate through the year (HR Wallingford/DFID, 2003 p. 25). From the study of the Umvumvumu monthly flow records, the lowest flow months are September and October, whose median flows expressed in l/s are 435 l/s and 379 l/s respectively. Using the lower figure, and adding the preferred water allowances for downstream of 120 l/s, provision for aquatic ecosystems, might require a downstream flow of some 500 l/s from this gauging station, to ensure for all rights granted. In the meandering low flow streams that occur in these wider river beds, such a flow would also be easier to train such that the irrigation scheme could abstract its water right. Of course, provision of flows for aquatic preservation that are twice that allowed for the irrigation system could be controversial. However, the incidence of these flows can be studied further to demonstrate the stresses emergent in the river system.

⁷ The Chakowa system has dropped a planned irrigated area because of water shortage, and even a night storage dam has not relieved water shortages that account for differences in head-tail crop patterns and timings, with head end areas particularly growing tomatoes. The records in the 1980's have not indicated any variation in intake since 1989, but this may be due to recording procedures as manpower has declined, rather than systematic full use of available water (see Chidenga, 2003).

As discussed in Table 7.2, water planners had taken a conservative estimate of water available for allocation. For unregulated flows, allocation could be estimated against the baseflow of the annual hydrograph at 10% risk (Ministry of water Resources and Development, 1985). In fact, there was discussion at one time of shifting this to 20% years, where there was greater storage.

However, the critical issue was availability of storage that could bring greater security about decision making. For rivers without much available storage, such as the Umvumvumu, planners had instead either to plan from lower probabilities, or rely on controls of abstraction so it was adjusted to available flow. Thus, as well as a priority rights system, many irrigation offtakes had a sliding right, where farmers could only abstract a higher flow when a given level of water was available in the river.

As this chapter has already suggested, sliding rights with use related to available water supply did not work well. Where farmers were coordinated with specific legal rights, they could perhaps negotiate with each other on the sharing of flows in a dry year against compensation in another. Around the world, many large irrigation schemes have rules and procedures in place for restriction and sharing of water across systems when flows are low, under central direction (Wahaj, 2001). However, smallholder black irrigators in communal systems had no individual rights to negotiate from. The authoritarian management of farmers within irrigation systems and relatively recent evolution of these systems meant few internal sharing and enforcement mechanisms were in place when droughts hit (Chidenga, 2003; Manzungu, 1999).

Manzungu (1999) described how farmers in irrigated blocks in Mutambara with contracts on crop production tried to negotiate with other farmers within the system to get water to save their crops (as well as police their water supply), in a drought year although this did not work successfully. Chidenga (2003) described how farmers from tail end block in Chakowa sometimes found employment in blocks with better water

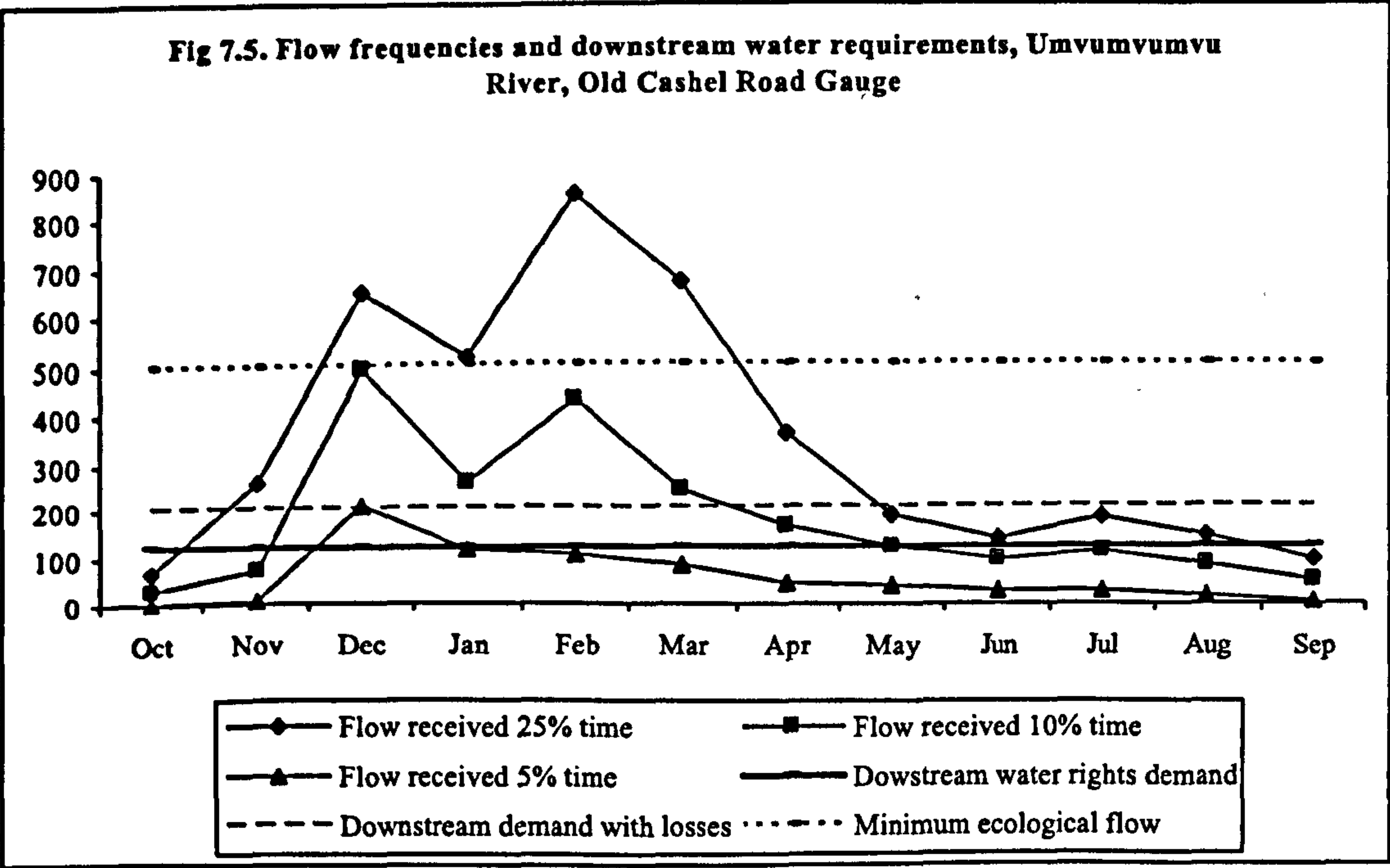
supply as a kind of compensation for the disadvantage that head end blocks caused by taking available water. Also, farmers in the upper catchment would not always voluntarily reduce irrigated areas if flows were low (or were forecast to continue low). If too many rights were issued upstream, there was a chance that the tailend of vulnerable systems (like Chakowa) would get inadequate water very frequently. Section 7.3 showed that, even with strong rules that illegal offakes could be destroyed and overuse of water could be prosecuted, and manpower to enforce this, there were regular problems of supply for downstream systems that fuelled struggles and disagreements over water between smallholder and commercial irrigators, and between their respective administrators (Bolding, 2004; Chidenga, 2001; Manzungu, 1999; Zaag and Roling, 1996). However, there were also struggles within irrigation systems about the areas that could and should be irrigated if water supplies were inadequate.

One way round this problem could have been some compensation arrangements for land not irrigated by those who took larger amounts of water and who could still irrigate in a dry year, or a combination of other employment and livelihood assistance. This, however, would require substantial organisation and a high degree of trust and negotiating capability to deal with estimations for compensation and losses of cropping investments undertaken. From the 1960s onwards some government officials were skeptical about smallholder irrigation development as a viable and profitable development strategy (see Manzungu, 1999 and Chidenga, 2003). This would also have limited government action to help formulate relevant financial and investment sharing mechanisms.

Also, many small producers relied on irrigated areas for their subsistence crops, and any compensation or insurance would need to assure these needs. They would still struggle to grow these with available water. Growth of additional crops for sale would

be additional to this, and subsistence cropping only abandoned if income was sufficient to purchase food needs and their availability was secure.

One standard hydrological technique that can be used to study over-allocation is a flow frequency curve. For the reasons just described, the different possible minimum flows discussed above are plotted against the flows received 95% , 90%, and 75% of the time in Fig 7.5, for the Cashel Road gauging station in mid-reach of the Umvumvumu river - downstream of which are a number of offtakes for irrigation, for three levels of low flow.



A comparison of these plotted lines shows how risk levels shape the potential cropping season length and thus what crops might be grown. The 5% flow frequency shows that in one year in twenty, flows will be inadequate almost throughout the year for the registered water rights. In such conditions, December-January were the reliable months to crop, with risks to receive inadequate flow for the Chakowa irrigation system even in late January. The months of December-January, then, are when most subsistence farmers will focus their subsistence crop. Farmers in the disadvantaged

tailend blocks only irrigated then in Chakowa in 1998/1999, and irrigated maize only. They did not risk sowing any other crops for irrigation at that time. The opportunities for more lucrative horticultural crops that could be grown March-October is indicated by the frequency curves for higher risks. At a risk level of one year in 10 the low flow period runs between late-April and November. In 1999, the headend irrigators grew more lucrative crops of tomatoes, onions and beans in March-May 1999, able to rely on taking more water but also having more links into market production to sell these crops. The tailend blocks only sowed some beans from April-July 1999. Looking at the flows received 25% time in comparison with allocated rights, only mid-August through to end-October appears as a dry period, and in fact this was anticipated in commercial irrigated farming system design by large and small farmers. Headend smallholder irrigators cash-cropped a lucrative okra crop, and groundnuts and maize in the period July-September 1998, and beans, tomatoes and onions March-July 1999, when there was water. Tailend blocks cropped beans between April and July 1999 only as water was available. The possibilities for cropping in July-October in the dry (and cool) season were fairly clear from flow and recession characteristics, so did not have risks of losses of sown crops. Smallholders were not risk averse as such, but the 5% criteria did demarcate the more secure period when farmers still grew a subsistence crop. Their production choices on other crops were shaped by their understanding of the security of water supply. (Crop information from Chidenga, 2003).

The graph of 25% probability against water right comes close to the approach of mapping the dependable moisture availability as it was developed by Hargreaves (1967). No graphs were made for higher levels of risk, such as the 50% value used for assured rainfall in India (see Chapter 3). This would suggest that water was available across the year at this risk level, but give no indication of the incidence of particular problem points in the cropping season or runs of years with low flow. Also, the

institutional stress of dealing with disputes on average every other year, if all farmers tried to plan to use more water, would be too great to handle. While some irrigation systems have often differentiated areas with seasonal and permanent rights to irrigation (as in Pakistan, see Wahaj, 2001), this would have been hard to formalize or enforce in the smallholder politics of Zimbabwe.

Considering the situation with an allowance for aquatic ecosystems, with a downstream requirement of 500 l/s, then actually there could be problems April–November, and in January, at a frequency of one year in four. Its enforcement could jeopardise several of the lucrative crops that smallholders tried to crop at these times, and it would be unlikely that such a flow would remain unchallenged or unused as it flowed past a scheme with considerable internal water stress.

From the perspective of the risks a commercial farmer might manage relative to their dry season (winter) crop choices, the Umvumvumu was not extensively over-developed. However, from the viewpoint of smallholders, the river was already developed to a level where the frequency of longer dry spells brought limitations into the irrigated cropping options of many downstream irrigators. Also, the differentiation was coming between smallholders and not just between smallholders and commercial farmers.

A second common analytical technique – on lengths of periods of low flows – bears out this probability analysis, and also shows the utility of looking inside general risk data to see the actual problems. Table 7.11 shows the length of spells with flows under 200 l/s. Years with serious dry spells often follow each other in a 2–3 year run. These occurred at least once in a decade, when there was also a dry year in which flows could be inadequate from January. Years with dry spells starting in May appeared to have become more frequent, and these years often followed each other, interspersed by runs of wetter years. In the 1990's, low flow spells tended to run increasingly into

November and December and thus had a much stronger effect on production scheduled in October-November.

Table 7.11 Numbers of days in spells with flow below 200 l/s, Umvumvumu river, Gauge E125 (Date is start of spell, followed by number of days (d) of low flow)

YEAR	DRY SPELLS FLOW < 0.2 m ³ /s (spells with less than 5 days higher flow)
1971	Aug 3: 106d Dec 6: 6d
1972	Nov 17: 7d Dec 28: 4d
1973	Jan 1: 31d Feb 8: 8d Mar 3: 269d
1974	-
1975	-
1976	-
1977	Missing
1978	Missing
1979	Missing
1980	-
1981	-
1982	-
1983	Apr 19: 223 d Dec 28: 4d
1984	Jan 1: 78d May 8: 185d
1985	-
1986	-
1987	Mar 23: 249 days
1988	
1989	Broken record
1990	
1991	May 23: 223d
1992	Dry throughout year
1993	May 8: 199d
1994	May 9: 174d Nov 7: 39d
1995	Jan 28: 314d
1996	Sept 12: 65d
1997	-
1998	Part missing
1999	Part missing
2000	Cyclone Eline destroys gauge

(Source: Daily flow records, DWR)

I end this section with a restatement of the problematic for the Lower Odzi watershed in 1998.

WATER RESOURCES PLANNING DATA

- mean annual runoff (estimated)
- 10% 'safe yield' if all storage built

000m³
235600
134300

STUDY DATA, YEAR 1999

- reliable runoff
- water rights allocated and supposed in use
- unregistered garden and riparian use

?
12910
?

Superficially there seemed little problem in the watershed when viewed from the ‘sub-catchment’ perspective. This study of local realities showed otherwise.

7.7 CONCLUSIONS

The colonial history of Rhodesia gave shape to longstanding Ministries for Water and Natural Resources that has allowed for cognitive and technical norms to become embedded, shaped by scientific networks and links with international scientific communities encouraged under post-war colonial administration and academia. The water agencies and legal developments of Rhodesia/Zimbabwe show particular systematized approaches, very related to more normative models of hydrological analysis and hydro-meteorological networks evolved for ‘developing countries’. While independence helped to redefine the ‘purposes to be served’ by science and technology and Ministries gave more attention to smallholder agriculture and irrigation, no new technical norms were defined. Rather, the ministries continued the scientific tasks of the hydrologist set many years earlier. The new Catchment Councils generated new hope and enthusiasm but later faced troubles to develop new procedures in the face of financial and political difficulties.

Looking back at Kohler’s model of what hydrologists do given in Chapter 2, Zimbabwe simply continued with technical norms relevant to particular tasks the state thought should be served – for agriculture. For planning and design, it focused on studying available water supply in average conditions. For operational dimensions, it looked to dam operation and scheduling of diversions and distribution for irrigation in the short term, and for agricultural planning in the seasonal and longer term. Information relevant to allocation and equity concerns – including on the variability of flows relative to allocated rights – and risks to smallholders – were never considered.

Returning to my own framework, in the older state agencies, historically both cognitive and technical norms were strongly controlled by scientific and political elites. The new Water Act has given more attention to local representation, and cognition outside these technical and scientific elites. However, so far, only 'formal' representatives of civil society are present, and in very small numbers – as tribal representatives for the communal areas.

Finally, returning to other concepts and models discussed in Chapter 2, the knowledgeability and capability of agencies seemed mainly related to land zoning and allocation and encouragement of more intensified commercial farming in agriculture, and regulation of larger rivers in water development. According to Roling's models, agent-context-ecosystem associations gave quite consistent cognition for commercial farmers, and there was coherence and correspondence in knowledge and institutional design for commercial agriculture and larger-scale river basin management. The 'capabilities' for working with small black farmers were present in agriculture, but variable in strength and usually very authoritarian. This chapter shows that this interest in smallholders was only partially present in the planning of water resources, despite the recognition of communal representation in the evolving water laws. There is now an urgent need to develop new coherence and correspondence between knowledge and institutions for contemporary water management that gives more attention to local rivers and smallholder users. Currently there is still 'multiple cognition' in cognition on surface water drought in Zimbabwe, and much work is still necessary to develop collective cognition. For myself, this study taught me yet more about the diversity of cognition that can exist between stakeholders, and just how politically created this can be. Also that building process for change is one of the most significant and difficult elements in building new collective cognition.

In 2000, the understanding of Zimbabwean rivers was still drawing on data information networks developed in the 1970's, without reference to any population, land use and climatic changes that may be affecting water flows. Contemporary calculation methods for the analysis of surface water supply at catchment and sub-catchment level paid little attention to the quantity and variability of flows in individual streams, although the reliability of water entitlements for small-scale irrigators depended on this. Upstream and downstream users were differentially affected by this variability especially at times of low flow.

The new Water Law will solve some old injustices, but it may not remove some inherent confusions still entrenched in the law. I hope it does not set smallholder against smallholder, nor smallholder against commercial farmers. In the same way, hydrological analyses currently used may not help answer questions related to reallocation. The reallocation of water rights has to be studied against the spatial hydrology of the main rivers, their major tributaries at key points, and their behaviour at high and low flows. The 1998 Law created a means to confront the structural water scarcity present in the watershed, in its removal of the prior rights systems and licensing approach. However, it has not yet address the differential risks of lack of access to water at low flows between smallholder farmers, as well as small and large farmers. This chapter thus also shows the difficulties in addressing the second-order scarcity issues related to management when there is structural scarcity – and that new technical guidelines and norms are needed, and not only new representation and institutions.

Most hydrologists believe that their first responsibility is to collect the best possible data and develop the most accurate scientific analysis of water resources. But hydrologists are part of society and, therefore, should ask the question what purposes do their analyses serve. This chapter showed that in Zimbabwe, hydrological analysis

had been done largely for land settlement and segregated agricultural development purposes, with a major emphasis on dam development relevant to capitalised commercial farming enterprises. While it was clear that dams could ensure more secure water supply in the Lower Odzi watershed, there was still a need for better analysis of flow variability to help design new allocation principles and guide a new allocation of water permits – the new operational needs.

Looking at the way collected data has been analysed and used, some strong biases and gaps seemed to emerge. First, hydrological analysis had focused on data analysis and equations expressing average runoff per area and equations useful for small dam construction. Here analysis was about seeing ‘available water potential’ in relation to very specific regulating technology with a clear and verifiable volumetric dimension that can be monitored and charged. This technology, like water rights, was vested in commercial landholders. However, this did not reflect the reality of smallholder water use still registered under communal lands either through smallholder irrigation systems or very small offtakes of 1l/s or less which were very hard to monitor. The unclear situation of gardens in primary rights, a key area of smallholder water use, was another complication.

Second, population and water use had changed. New needs in forecasting to guide allocation in low flows suggested not only a need to study the relationship between rainfall and runoff better, but also to understand the relationship between water resources and land use in a catchment. In this way better support services could be provided to both smallholders and commercial water users. The analytical methods were not specifically designed to analyse characteristics of surface water drought level of risk, but were more for general planning. They failed on the critical issues of allocation and operational decision-making related to short-term forecasts. They thus really were not useful tools in relation to the stresses of reallocation arising by 1998.

New initiatives that could help include more analysis of flow variability to find new allocation principles for low flow, and more studies on rainfall and runoff to facilitate forecasting and increase understanding on how water regimes might be changing with population increase and changing agricultural patterns. However the relations between irrigators within systems and along a river also need attention to start new thinking about risk and local action when there is competition for water. Irrigation development, while a key framing element in cognitive norms, was no panacea against surface water drought, while there was no sound appreciation of the risks in its water supply.

CHAPTER 8

CONCLUSIONS

Viewing (drought) as a visitation of nature only diverts attention from a whole range of social activities that intensify or mitigate its effects...What is required is to highlight drought as the central problem of development....If this is not done, it will continue to be treated the way it is with a few long-term projects, little investment and inadequate efforts to search for scientific and technological solutions to its problems. Agricultural development requires an entirely different perspective and policy effort...has to be reviewed to keep drought as a central focus. Mather and Jamal, 1993, p. 118-125

Where meaningful interactions are suffocated by unconscious collective images or pre-understandings that demand articulation, reflection and critique, there is a legitimate task for critical science. Empirical analysis of data, skilful interpretation of socially constructed meanings and social critique are equally important elements of an enlarged concept of scientific rationality....Rationality as openness to learning further presupposes the embeddedness of the scientist in a durable context of dialogue and action Hoppe 1999, p.203

8.1 INTRODUCTION

This study set out to understand why, despite more than 100 years of public concern, planned intervention and investigative science in droughtprone areas, the water resources in such regions are overallocated and have unequal access, and significant inequalities and vulnerabilities remain for farmers. It tested two related hypotheses to explain this. The first was that scientific, technological and political elites built their profiles, or struggled to remain prominent actors, through the technical and cognitive norms that they built. Development of these profiles was often promoted with assumptions that it would bring social legitimacy as well as both outcome and social power, but often did not. Secondly, that a cognitive framework linking scarcity and drought - rather than drought or scarcity alone – can transform options to discuss water resources, their allocation and their monitoring.

Through case studies in different droughtprone and water scarce areas in different states, dependent on different water sources, this thesis has studied how different states of development shaped the occurrence and relative power of public agencies to manage a water cycle prone to fluctuations and deficits. These elites took different forms in

shaping access to water: technoscientific agencies and technoeconomic networks as in the Indian case studies: civil society elites and communities as in the Yemen study: and technoscientific and legal agencies within the state apparatus of Ministries and Water Courts as in the Zimbabwe study. They also had different cognitive and technical norms in looking at drought and scarcity contexts, and within this a different emphasis on scientific and popular knowledge, and different levels of commitment to cognisance and conscientisation. Key differences and opportunities emerging from this analysis are given in Table 8.1.

These conclusions first summarise key findings across the case studies relative to these hypotheses, by revisiting the research sub-questions. It then looks further into the societal challenge for states in (re)organising water knowledge and management. Finally, it revisits the three objectives of the thesis to show the usefulness of a cognitive framework: in improving reflection on water resources planning in droughtprone and scarcity areas; in planning of participation and negotiation around drought and scarcity problems; and in recognising potential for transformation in public action within the resource-technology-society nexus in water-scarce areas.

Regarding the profile-building of agencies, those with established scientific orientation and resources for actual field verification in data collection have continued to stay in existence and retain recognition, even if they also still attract criticism of their approaches. Once resources and credentials begin to slip (or are never established), then their data becomes of uncertain relevance. Any power to make a valid contribution collapses (along with continued funding to do it), but so too does the power over actions as rules and procedures that permit water access become flouted. I hope that future work and contacts in all these states will help reflection on scientific and cognitive norms that will address contemporary problems, to move beyond the defence

of norms repeated in the interests of routine operations and necessary demonstration of task performance for agency survival

Discussion of the different case studies emphasised that drought does have different dimensions and manifestations, of which continued and improved understanding is needed. Cognitive frameworks on drought have made attempts to understand effects of lack of rainfall on different elements in the water cycle – soil moisture, groundwater and surface water drought, but largely in relation to defined risks of water deficits and perceived options for technologies to increase access and production opportunities. While wider calls have come to recognise the range of social relations and activities that exacerbate or mitigate drought effects, few scientists in national agencies have widened their work to study such processes. Frameworks of scarcity – more related with access to and use and management of water - have changed in their emphasis and specificity over time - from a focus on the lack of security and economic opportunity shaped by lack of water availability and the sociotechnical design of water control that mediates water shortage, to specific attention also to structural scarcity where vulnerability and marginalisation is created by social relations of exclusion and second-order scarcity created by inadequate management capacity. Scarcity perspectives were coming to dominate debates about needed public action by 2002 in droughtprone areas, because they connected more with the real experiences on the ground. However, they have hardly impacted back into the norms of public agencies, to change their routines or contact with the public, such that scarcity dialogues seem either developed in new civil platforms or direct action. Thus the various cognitive frameworks for studying drought and scarcity have still hardly come together yet to reshape public action, although there could be great benefit from this.

This thesis has shown a sad materialisation and domination of largely simple mapping and patterning techniques from scientists to assist public agencies in

droughtprone areas. Efforts for increased understanding of complex social and environmental processes shaping drought dimensions remain rare. Yet this thesis has shown that there have always been further analytical and investigative techniques possible to give greater attention to the use and the user of the water who is so affected by drought. In addition, the study of scarcity in relation to actual water access as mediated by technology and institutions also remains quite rare, and this thesis has aimed to show the importance of understanding actual water availability and access rather than generalised mapped conditions created by certain discourse around scarcity. It is communities accepting collective cognition and will in mediating access that have showed best capabilities to survive. These have often come from the driest areas and most vulnerable communities, if they have built up a political and legal capacity to manage their technologies and water cycles, as in Yemen in the past. Ironically, here recognition of tacit and popular knowledge rather than expert science has often proved more critical in shaping these possibilities – in which space for negotiating disputes, as well as space for knowledge exchange were important. Most agencies for science and technology have focused into maximising supposed water potential, continuing a ‘supply-side’ focus (Sexton, 1990) into with new concerns around productivity of water and risk survival, beyond simple water availability. Few have considered new approaches to design with reference to actual demand-side realities (where demand is politically and technologically mediated and not just exerted by crop choices) or realistic local matching of technologies and institutions, emergent from a particular society’s use and management of resources in economic change.

Table 8.1 Working with drought – science and agency in different states

STATE	FAILED DEVELOPMENTAL	WEAK	AUTHORITATIAN/PATRI MONIAL/ UNDERDEVELOPED
Social mechanisms			
Agencies	<p>technoscientific agencies</p> <p>planning agencies</p> <p>venture agencies</p> <p>techno-economic networks</p>	<p>Turnkey-type agencies administering own programmes with weak central link</p>	<p>Technoscientific government bureaucracies</p>
Civil society	<p>NGOs</p> <p>Formal and informal elites</p>	<p>Communities and customary law</p> <p>Informal elites</p>	<p>Formal elites</p>
Knowledge And specialties	<p>Rational science informing formal elites</p> <p>Technology often driving scientific questions</p>	<p>Tacit knowledge and power with customary roles</p>	<p>Rational science informing formal elites</p> <p>Scientism in technology design and choice</p>
Key tools in mapping water resources needing new consideration	<p>Own data collection sites or generic empirical norms</p> <p>Quantitative techniques and criteria e.g. (for rainfall and groundwater)</p> <p>Annual rainfall</p> <p>Optimal Moisture Availability</p> <p>Specific capacity</p> <p>Groundwater estimation routines</p>	<p>Embedded in laws of water use</p> <p>Qualitative, cultural differentiation of sources linked with use</p>	<p>Hydrometric networks evolving in relation to commercial activities</p> <p>Quantitative techniques and criteria e.g. (for surface water)</p> <p>Mean Annual Runoff</p> <p>Runoff yield and risk</p>
Possibilities for learning and shifting to critical science and technology for studying drought and scarcity	<p>Negotiation around disputes and direct action</p> <p>Visioning and action research between users, engineers and scientists</p> <p>Consultation and strategies of improved communication</p> <p>Collaborative capacity building</p> <p>Rethinking local management – expert and local knowledge</p>	<p>Negotiation around disputes</p> <p>Participatory action research and development between users, engineers and scientists</p> <p>Recognition and discussion of how collective will is imposed</p> <p>Rethinking controls on technologies in new forums</p>	<p>New representation after political reform</p> <p>Visioning and dialogue between users, engineers and scientists</p> <p>Special assistance programmes</p> <p>Rethinking representation and the management and assessment of water resources</p>

8.2 SCIENCE, TECHNOLOGY AND AGENCY IN WATER DEVELOPMENT IN DROUGHTPRONE AREAS

8.2.1 Cognitive rather than instrumentalist frameworks in policy-related research

The need to change from instrumentalist to more interdisciplinary and socially aware research questions has been an important theme of this study. All the case studies have shown that an instrumentalist perspective, where water availability alone is seen as the deciding influence in development, is insufficient to give understanding of how farmers and agency workers make choices about how droughtprone regions may transform. However, too strong a focus in political economy in action can highlight the power struggles between actors within social relations of resource control and technology choice, but give insufficient attention to the transformations in resource monitoring and assessed, and how technologies can be chosen and (re)designed.

Approaching a droughtprone area as a cognitive space allowed it to be seen as a space in which new knowledge, technologies and related social relations can be created, but also as an arena of actor strategies, actor networks and struggles about knowledge and control. The approach became a means to integrate understanding from both the political economy of natural resources and also awareness of the social construction of knowledge, resource dynamics, social pressures and technology design.

The case studies have shown that where technoscientific agencies gain control over the monitoring and allocation of resources, cognition is restricted heavily into dimensions of cognisance. In the agencies studied in this thesis, there is really very little conscientization towards either participatory technology development, or concerted action to manage resources. This has only changed where external pressures and new funding allowed space for new action, and when endorsed by peers. In the cases of the positive developments of participatory hydrological modelling and

hydrological audits in Andhra Pradesh, these have gained recognition by many, but their continuation will depend on institutional reforms and facilities in wider local government, as well as within the technoscientific agencies. The science of these agencies has often been very structured by what data and analytical processes the technoscientific agencies will accept, as shown in both the Indian and Zimbabwean case studies. The Yemen case study and the Indian village study of section 5.5 showed that local actors can develop institutions and popular norms for development and management of their water access technologies without sophisticated science, but this does take time.

Revisiting the typology of Brooks (1994) on the relations of science and technology (see section 2.2), to link these with agency, this thesis shows that technology has driven development of science in the droughtprone areas far more than vice-versa, even though new specialty agencies and their research agendas were justified through the need for new knowledge for resource development. It has also been the development potential of irrigation and water conservation technologies in droughtprone areas that has driven the type of questions asked about water resources in droughtprone areas, and justified finance spent on these agencies. Science, in the case studies of agencies here, has been largely used as a tool in mapping resource modules to calculate the numbers of technical artefacts possible, or statistical analysis to define physical allocation, rather than a means to really rethink water management collectively. This also confirms Nightingale's (1998) definition of science and his justification for taking wider cognitive approaches when looking for innovation possibilities.

8.2.2. Changing definitions of drought and changing emphases towards scarcity

It has proved important to look at drought in relation to different elements of the hydrological cycle – rainfall, groundwater and river regimes – this can demonstrate the behaviour of the resource in its physical context and how this is related with the technologies to extract it, and how water availability shapes its use. The chapters have shown the value of looking at the nature of dry periods and perturbation in a water source as well as generalised measurements of the water cycle. All these can be better related to the technology of access and the differential options of users within water systems – sociotechnical systems – that shape and are shaped by the natural water cycle and the social relations mediating access to it. In this respect, moving from a focus just on meteorological drought to more specific attention to agricultural drought, groundwater drought and surface water drought has given some specific reflection on the relations of users-technology-resource management. However, a ‘scarcity’ perspective is still needed, that can move understanding beyond the narrow physical assessment of ‘human impact’ in shaping how rainfall is related with other water sources with actual water availability patterns, and any related search for generic tools to lessen this impact. What is needed rather is a scarcity reference that opens up the understanding of social processes acting across state and locality to open understanding of local water access as well as use under local scarcity contexts – and through this the different challenges to different groups to find strategies of transformation.

However, attention to drought specificities also helps to ground studies of water scarcity, which can also often lose their reference to actual local water environments and local strategic choices under larger-scale studies of basins or national economies. Transition-type models of water management stresses in river basins and groundwater use (Burke and Moench, 2000 and Keller et al, 1997) have their uses to identify future

needs in public action, especially when they are related to the polity and water resources of that location, but the differentiation of access and livelihood strategies locally can remain masked. Making water work, from the bottom up - as opposed to hypothesising plans of how it might flow, from top-down - requires some new concepts for the droughtprone areas. Rather than searching for a single indicator, studying a drought-scarcity nexus, through a matrix of the kind applied in this study and initiated in Table 2.1 can be one new approach. I return to this in section 8.3.3.

A cognitive framework that focuses only on physical dimensions of drought and lack of water as a condition tends to link with a very narrow analytical focus into the physical ecology of a locality. A cognitive framework focused from a concept of scarcity brings a focus on the economic and societal dynamics playing in the region, to portray a social landscape of institutions, property rights and social relations rather than just the physiographic landscape and hydrometry. However, both can integrate around understanding of environmental and social processes linked with drought to reshape public action more effectively. Such action can then move the common development focus from agencies and knowledge to mobilise, increase and secure supply, to a better understanding of interactions between societal needs and the dynamics of water resources -as shaped by natural mechanisms, technology and people.

8.2.3. Evolution versus stagnation in the cognitive practices of water elites

Few of the specialty agencies documented made any shift in their analyses without a radical change in political context - perhaps because their identities were so bound up in a specific domain related to water resource assessment or extraction. The scarcity framework that is now coming more into use is often directing change into core local socio-spatial organisations - like the district collectorate in India who will manage

hydrological audits, the local councils in Yemen and the representatives and managers of watersheds in Zimbabwe – which experts will advise only. I hope there will be more reflection in the future on how this can work better for all groups generating knowledge and supporting its use in rural transformation, for which this thesis has given insights.

The case studies have showed that all elites dominating water management do develop their own technical and cognitive norms, but there are real differences in how these actually become accepted and embedded. Agencies which can control their own monitoring and data collection, and are resourced sufficiently to do planned research (like IMD and ICAR) did develop their own norms, which also became widely accepted within them. However, other agencies simply continued use of very simple empirical norms and equations established out of necessity early on. In this respect, deriving accepted and respected norms is much easier when science does try to shape technology, and much more difficult when the technology is already on the market.

All forms of agency could have used a range of information collection and analytical methods. Much of the detail in this thesis was to give a demonstration of what analyses could show social concerns and risks better in particular drought and scarcity contexts. However, their choices of routines were often biased by economic priorities and analytical preferences acceptable to the agency. All the agencies studied have shown disciplinary/specialty isolation and it has been a struggle to involve them in wider perspectives. In this respect, it is important to note the different wider frameworks that have begun to influence agencies dealing with different water resources/water use contexts. Farming systems perspectives have been used to broaden research in meteorological and agricultural drought studies, while livelihood perspectives have been used as a wider framework for groundwater and surface water drought. Scarcity is a perspective that enables integrated understanding of different water sources as well as social uses, but remains a real challenge for specialty

organisations in hydrology and geohydrology, and perhaps this is why it has been driven more by external studies rooted in wider local governance entities and NGOs.

For myself, charting my own history reminded me of the transformations I had to make, to be a critical scientist rather than just rational one:

- from mapping only the physical drought and scarcity in the water resource, to including the user of the water resource in different dimensions of the water cycle:
- studying the processes linking different forms of drought as they are mediated by technology;
- to studying the 'guidelines from the resource' in how it shapes artefacts of use, and social relations around them, as a means to rethink access options to scarce water;
- to joining new dialogues and debates around new knowledge, but also understanding the limits in individual scarcity 'discourses' and solutions they may prescribe;
- to recognising that public action in water scarce regions is political and not always rational, and that participation in real intervention engages one immediately in real water politics.

8.2.4. Diversity in public agency in droughtprone areas – learning from differences

The case studies have demonstrated the capabilities (and limitations) that can come from a range of collectivities striving to work in water development – technoscientific agencies, technoeconomic networks (departments and corporations), and village-level management and governance institutions. As Chapter 1 cited from Long (2001, p.16) collectivities become agents when they have discernible ways of formulating and carrying out decisions, and have both knowledgeability and capability. The case studies show that these concepts of knowledgeability and capability do have to be translated

culturally and politically, to see the form they take in different states. Thus there is no ideal norm in assessment or management procedures for droughtprone areas. What is critical, however, is the way they build in a participatory dimension that allows a structured debate, and whether this emerges through consultation, interactive communication, dispute or direct action. Table 8.1 shows that I see very different locations and activities for such work in the different states. I hope this can become the point of change for scientists to move from rational to critical and postnormal science as the opening quote from Hoppe (1999) highlights. They will need this to play a valuable role in the new decentralised forums for water management – and in that respect may still need to learn how to embed themselves in dialogue and not just in scientific and institutional politics. Table 8.1 summarises different tools that may yet be used by these agencies to make them ‘learning organisations’.

It helped to study the practices and actions of agencies in relation to actor networks. For the evolution of some technical norms, technoscientific networks did evolve in some cases, as between IMD and ICAR to define risks to help design new on-farm technologies. However, overall, technoeconomic networks proved much more influential on actual resource assessment practices, and selection and siting of water technologies - where powers to development and manage technology and resources were shaped by financial, social and political links. States with developmental aspirations showed the strongest mix of specialty and civil agency – in weak and authoritarian states only one of these tended to dominate. Only developmental states used agencies like ‘venture’ corporations or relied on markets and the private sector in policies for transformation of their droughtprone areas.

Overall, departmental structures seemed to develop the most embedded and enduring norms, and also seemed to survive better both through their own political institutionalisation, also allowing such structures to link well with other funding and

scientific networks. The capabilities of organisations like APSGWD to survive, despite known problems in their assessments and monitoring, were remarkable. The corporation structure – as with the technology dissemination organisations in India – proved a problematic one for cognitive development and financial survival. Expediency drove early acceptance of very simple norms and procedures for which they later became greatly criticised. If APSIDC had developed a coherent institutional development programme alongside its technical one, able also to debate financial and rights issues, it might have fared better. Only after its virtual financial collapse did it open up to more participatory approaches and a concern for institutional development brought in by external assistance programmes. Changing governance structures in water management can give a chance to debate new cognitive frameworks, as well as representation, as seen in Zimbabwe. However this study also showed just how difficult it can be to ensure equity and social justice, in that in the new situation small irrigators may contest with other small irrigators as much as with large farmers.

8.2.5. Cognition about water supply technology and the analysis of resources

This thesis suggests that recognising the way technology shapes both resource use and social dependencies may give much more relevant ideas for the assessment of resources and design of support programmes in droughtprone areas and scarcity contexts. This is a different cognitive framework from hydrological analysis alone, which can develop analysis related to how people access and use a resource, rather than just collecting the best data and doing the most advanced analyses possible. All the case studies have shown that there can be different analyses to give more attention to needs of small water users, and the relation of access technology with resources, however limited the data. Developing capacities to work with multiple frameworks can help answer

questions about what we still need to know to alleviate drought impacts and manage scarcity better.

8.3 STATES OF DEVELOPMENT AND CHOICES IN MANAGING DROUGHT AND SCARCITY

Looking beyond drought, a scarcity focus can bring attention to the social resources of a society and its adaptive capacity in the way transformations in agencies, technologies and social relations of use can emerge. This again is why attention to the nature of the state is so critical. The case studies have shown a diverse range of states with very different development objectives and political purposes, and very different degrees of capacity to influence local realities. These in turn shape the elites dominant in water management and controlling access, and the institutional structures in place for water management. In this respect, there is no ideal model for planning intervention in droughtprone areas. However, this chapter summarise findings from three perspectives:

- Looking from the state, for directing the mobilisation of water for development
- Looking from the village and the system, for negotiating local water security
- Struggling in between, negotiating the drought-scarcity nexus in droughtprone areas.

8.3.1. Looking from the state, for negotiating water development

There are powerful economic choices and political motivations behind the design of data collection and analysis, and droughtprone and scarcity-affected regions generate powerful data collection dilemmas. Data generated has often tended to serve economic planning needs rather than technology design and local equity. In target-driven development planning, as seen in the DPAP and IRDP of India, technology choices often got shaped by wider financial and political forces, rather than the real resource

situation. There are choices in how regional political or agricultural development organisations, rather than hydrological planning institutions, shape water programmes. It is the real power of these institutions and their interfaces with villagers, that have major influences on village-level experiences and capabilities in resource management and technology use. The analytical and statistical approaches used to identify risks to production and availability of water by public agencies have largely failed to show the dimensions of scarcity as experienced by local people in their individual lives and social relations. These also fail to show how diversity of technologies in use is related with understanding of scarcity by local people, beyond the dominant forms promoted.

8.3.2 Looking from the village and the system, for negotiating water security

None of the case studies indicated much recognition of higher level hydrological authority at local level. People struggled and manocuvred with data designed on more scientific lines. Information and guidelines may be better institutionalised within simple guidelines, rules and regulations – as documented for local water management in Yemen and PHM in India. Both the Yemen case study and the Indian groundwater study also showed how village and community politics had to be factored into technology choices – technology is never simply handed out or simply accepted. Unpacking disputes around technology, and working with them as a social arena rather than a social problem, can be a powerful learning tool for individuals and local groups (if started before conflict erupts). This thesis has shown, like Mehta (1998) that local people do have diverse strategies and knowledge they used in the face of lack of water or restricted access. It has also shown how local practice in water rights is a critical source of information on how groups allow innovation in water use in spite of scarcities and drought risks, while keeping control of their water sources.

8.3.3 Struggling in between: negotiating the drought-scarcity nexus in droughtprone areas

This thesis has shown that it both possible and necessary to understand how contexts of scarcity inter-relate with different forms of drought if we are to understand the needs and strategies of water users. Also that these can manifest themselves particularly through the performance of technologies and agencies, which in turn relate with the reshaping and new differentiation of livelihoods and agrarian relations. Poorly-designed policies of technology development have helped to increase vulnerability to drought, and drive over-exploitation of water resources. However, Chapter 5 showed two significant cognitive shifts, in the use of biomass concepts, and in how water use can be mediated by analysis of the components of technology, and their redesign to transform social relations of water control (as for the control of electricity use).

In liaising between the state and the village, the district- or local river-level is a critical one in the design of water information systems and in building knowledge and trust between local people. Local government or system representatives and the front-line workers of agencies, are as important (and may actually be more important) than new basin level initiatives in representation and management. The nature of the expert system is critical, both in how it has developed its own norms, and whether it is prepared to accept its own fallibility and be open to both new science and more interdisciplinary and action-oriented research findings.

This thesis confirms some of the findings of Mehta (1998), that the value of a focus on water scarcity is how it brings attention to relational aspects of water use. However, we also need to take care about the biases a particular focus may bring. Mehta's work also asks to understand the relations that act across society, and between society and resources. We should not only target one context of scarcity and risk a mechanistic

portrayal of the experiences, strategies and knowledge of local people in getting water in relation to physical shortages which can have diverse origins.

The case studies in this thesis have shown that rarely was only one 'form' of scarcity in place but rather several came together. Rather it has shown that economic, structural and designed water scarcities can be better seen as sets of relations than broker access and performance, often through particular technical and institutional norms, networks and power relations. Thus rather than producing another new term to claim a more specific focus or integrative representation for water scarcity, an effective way to better understanding could be to explicitly focus on the social relations emergent through integrative study of forces in economic, structural and designed water scarcity. This helps understanding of the mechanisms and flows of power and resources that link them and thus shape action around an experienced water shortage. Returning to Figure 2.1, policies related to scarcity could also give better integrated attention to the focus public action – adaptive capacity, renegotiated governance, allocation and system design; and conflict resolution - rather than just focusing on one of these, as can happen if one discourse becomes dominant.

The diverse conceptions of scarcity in use – economic scarcity (where shortages and exclusion are seen in economic conditions and related with the key institutions mediating water policies and water systems for economic change: Government of Maharashtra, 1973; Sexton, 1990, 1992), structural scarcity (resource capture by elites: Homer-Dixon, 1995); orders and spirals of scarcity (emphasising first the physical dimension of scarcity then the second order scarcity related to lack of skills and adaptive capacity in public management institutions: Turton and Ohlsson, 1999, Turton and Warner, 2002); and system-embedded 'designed scarcities' (reflecting water allocation choices and relations acting through technology at scheme and basin level and shaping local action for water delivery; Wade, 1988, Uphoff et al., 1990; Vincent,

1991; Mollinga, 1998; Oorthuizen, 2003; Vincent and Manzungu, 2005) - all interact through the public domain and in public action around water scarcity in a state. The cognitive norms and their places of institutionalisation and practice in these domains of water control also reflect the priorities and relations of control acting across states, and can become a means to understand the actor networks, political mechanisms and new technology options involved.

The lesson from the cognitive history of this thesis is that more research and critical science is needed, to understand how these scarcity dynamics interact to shape agrarian as well as national economic transformation, and in turn reshape water cycles and drought events. For example, focusing on structural scarcity alongside designed scarcities shows the challenge to breaking economic scarcities present through the financial and political powers of elites – that might otherwise continue to subvert equitable water access to water resources, shape conflicts and limit creation of meaningful new scientific and technical norms in water allocation and operations. Attention to ‘second-order scarcity’ has also helped to bring special attention to the reform of public agencies and new platforms of social action related with scarcity of access and other injustices. However attention to this alone has a weakness in the way it can focus just on the ideals of new action and new structures, rather than the realities of local struggle in transformation in water use. It can still fail to address a to ‘third order scarcity’ for this kind of typology, that becomes clear with greater attention to designed water scarcities. This is the existence of differential risks, uncertainties, and injustice in access to water between users and differing ecological instabilities for them resulting from science, technology and agencies in control - that may still materialise even under transforming water management institutions.

Thus such a nexus and linkage approach enables a view beyond one dominant discourse, to see how the norms and claims within them still need to be debated and

contested. It thus also addresses difficulties in engaging explicitly in critical science and engineering to develop more inclusive and socially-conscious scientific and technical norms for facing water scarcity. Such a conceptual framework can start the more integrated study of drought and scarcity that many authors have called for.

Combined attention is possible to the physical shortage, hydrological linkages and social mechanisms shaping access to and use of different water sources in water-scarce regions, so we better understand people's coping strategies around drought dynamics versus exclusion from water, and where agencies might reform. However, I think we still need more work to understand the transformation of operational and design capabilities for limited water supply when recognising these scarcity domains, together with creation of new social mechanisms and platforms and direct action that struggle for greater equity and justice. This also links with the new scientific 'rationality as openness' referred to by Hoppe in the opening quotes.

8.4 MEETING NEW OBJECTIVES IN SCARCITY MANAGEMENT THROUGH A COGNITIVE APPROACH

8.4.1 Breaking narrow approaches to water planning

A cognitive framework can help a scientist and engineer in the critical study of their own knowledge and its relation with action and outcome. In this thesis, I have documented the following areas of critical reflection for cognition that could transform individual and collective agency, including:

- the basic understanding of consciousness and processes of knowledge growth and belief;
- the development of critical science to reshape the work of scientific specialities and agencies;

- the content of knowledge used in understanding, and how this is related to inclusion of different sets and forms of knowledge, different forms of representation, and different methodologies of research and knowledge generation;
- changing associative theories used to ascribe outcomes to certain relations and processes and cause with effect;
- cognisance allowed to determine utility or truth and propose action: and thus how certain knowledge sets, artefacts and ideas becomes instruments of public option, action and new knowledge generation;
- conscientisation on the relations structuring knowledge, power and control;
- cognition used in design and operation of technology and generation of knowledge around this.

When applied into the study of drought and scarcity these can give a better understanding of how knowledge relates with action and outcomes, and the spaces for change in institutions involved in development policy, implementing change and intervening locally. However, there has to be focus with water users for critical analysis of norms in place, to show the hydrological, technological and social realities in water use, and the interplay of collectivities, social arenas and public action around scarcity.

8.4.2 Understanding participation as struggle and negotiation as a process

In all the studies, despite different cognitive and technical norms in each type of agency, each also had a 'habitus', and it was usually external actors that tried to reshape these. However this reshaping can rarely be influenced by an individual, as my documented attempts show. Rather reshaping comes from concerted action in a broader social arena, as shown with the new water management institutions in Zimbabwe.

Neither the building of participatory approaches nor the creation of platforms for negotiation is straightforward, as especially the Yemen case study showed. The difficulties to appreciate and work with struggles and conflict, which emerge in any move towards concerted action, do need more attention. Either these may not be expressed well, or groups may use their own cognitive and technical norms as framing discourses that ensure their role in a debate but also protect their interests (even though these norms may be widely flouted in everyday life). Following Gigerenzer and Todd (1999) one tool is to look at the coherence (cognitive consistency) and correspondence (structural coupling of actors, social context of ideas and their domain of existence). This can help to see the realism of what people argue and say they may do, and the failures in coherent cognition that also includes a social dimension. Also a cognitive space (and development arena) like a droughtprone area can be studied for the diversity of cognition among agents within it. The study of sociotechnical processes around technology, and the actor networks that move water, are an important focus in this space (Mollinga, 1998). The differentiation of Roling (2002) between collective, distributive and multiple cognition is also helpful here. Better water management under scarcity at a local level comes where there is a collective cognition where rules can be enforced (as in Yemen in the past). However, the rapid social and environmental change in droughtprone areas has meant that such collective cognition has not had time to build. Instead there is distributed (or partial) cognition or multiple cognition that has led to the problematic programmes of research and development seen in the India cases, with their dialogues of the deaf between agencies, NGOs and farmers, and the invisibility of small farmers in hydrometric analysis seen in the Zimbabwe.

8.4.3 Determining that change can happen

The advantage of writing a history, that has also encompassed political and cultural diversity of governance, is that it can show how certain cognitive and technical norms evolve and how quickly they become embedded. However, the studies show that, if these norms do not change, agencies lose their reputation if not their existence. Changes in social order – whether in new structure of representation as in Yemen, or in new state policies as in India and Zimbabwe – do create times and spaces for change. In these case studies, no agencies have changed strongly from within - but new policies, new development frameworks and public opinion have helped create new frameworks for resource study, as shown with the hydrological audits and participatory hydrological monitoring in India, and new river management institutions in Zimbabwe.

8.5 EPILOGUE

I hope writing a study in this way helps to show the hydrologist and engineer the weight of social action to consider in their work. Taking time to track a cognitive history of the practices of their field and that are used in their region of work, to be aware of cognitive differences of those they strive to work with, and work with both critical and post-normal science and engineering in their agencies, may yet help build the equitable access, environmentally sound technologies and sustainable water development that people seek for the droughtprone areas of this world. Focusing on a third level of water scarcity, and the dynamics of social processes around water availability and norms to manage equity around it, can show scientists and engineers the need for dialogue and renegotiation around the norms used in drought and scarcity analysis. This includes an ability to recognise, address and adjudicate inequity and

injustice emerging in contexts of water scarcity also shaped by natural drought mechanisms, and to aim for negotiation rather than imposition of new institutions to resolve them.

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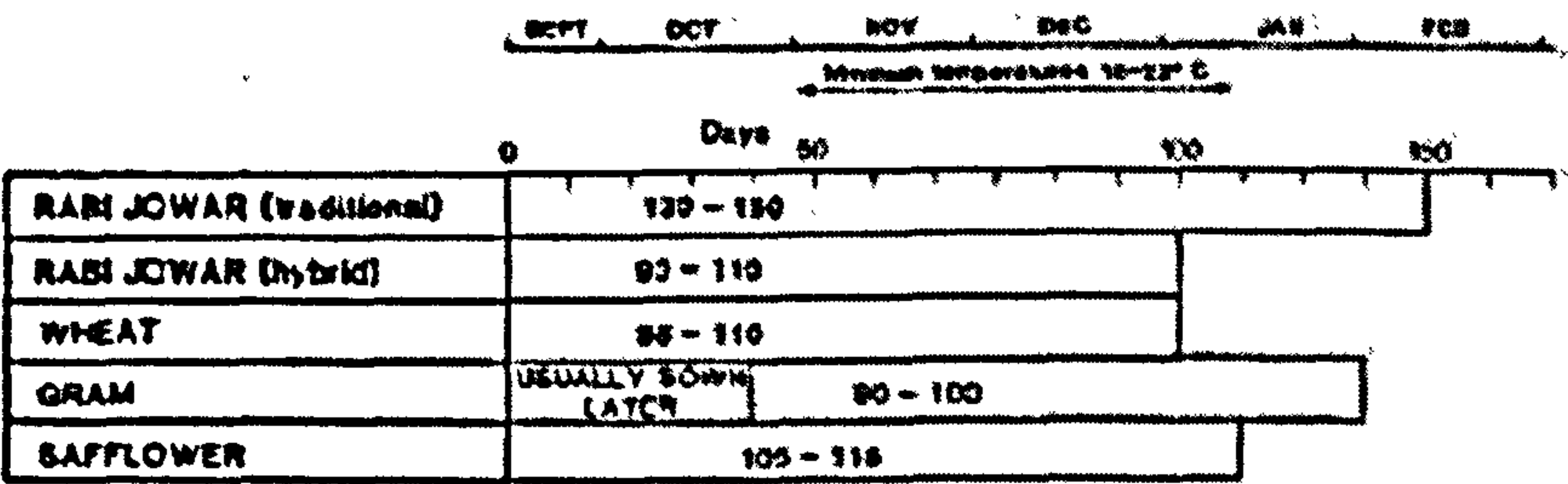
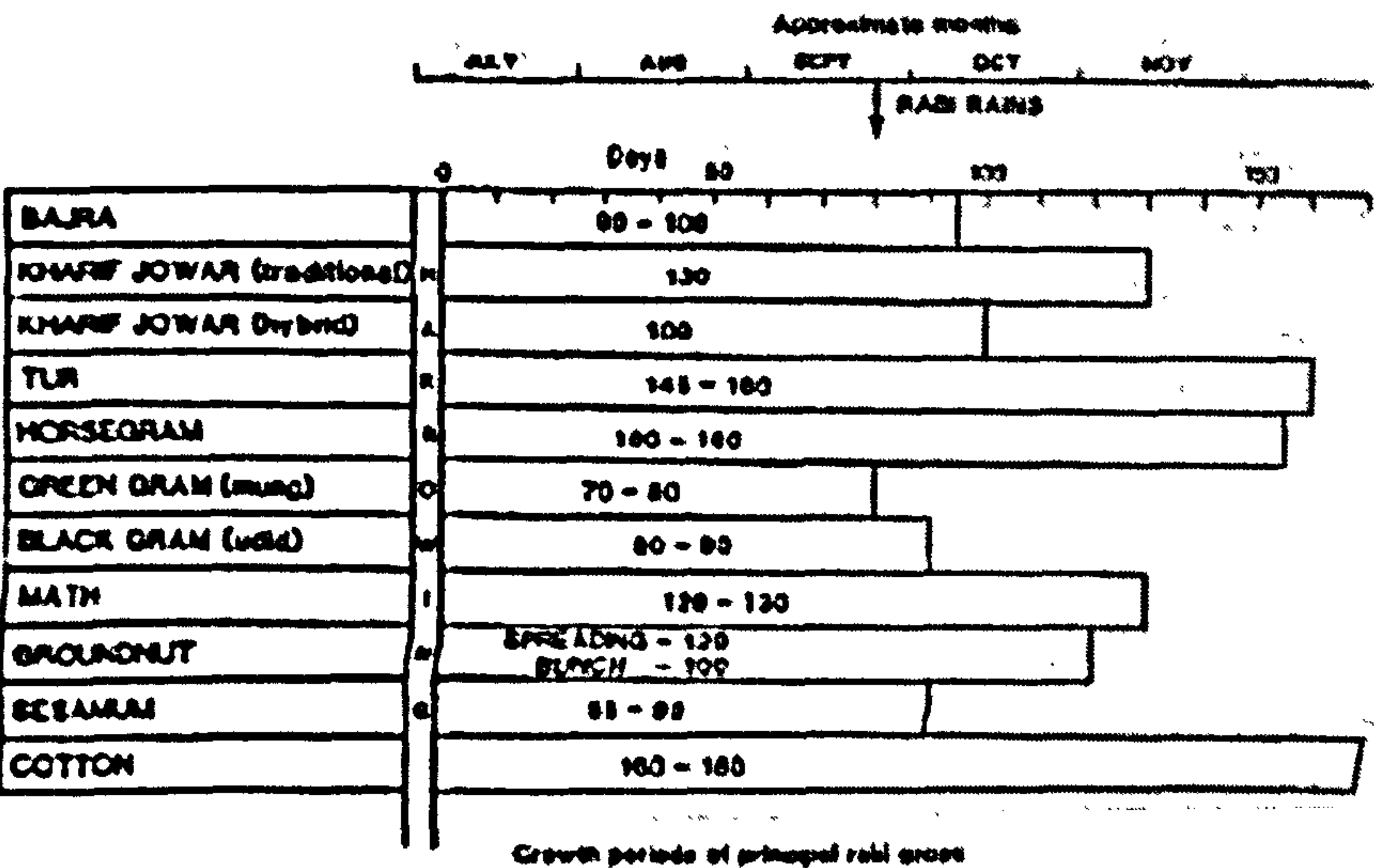
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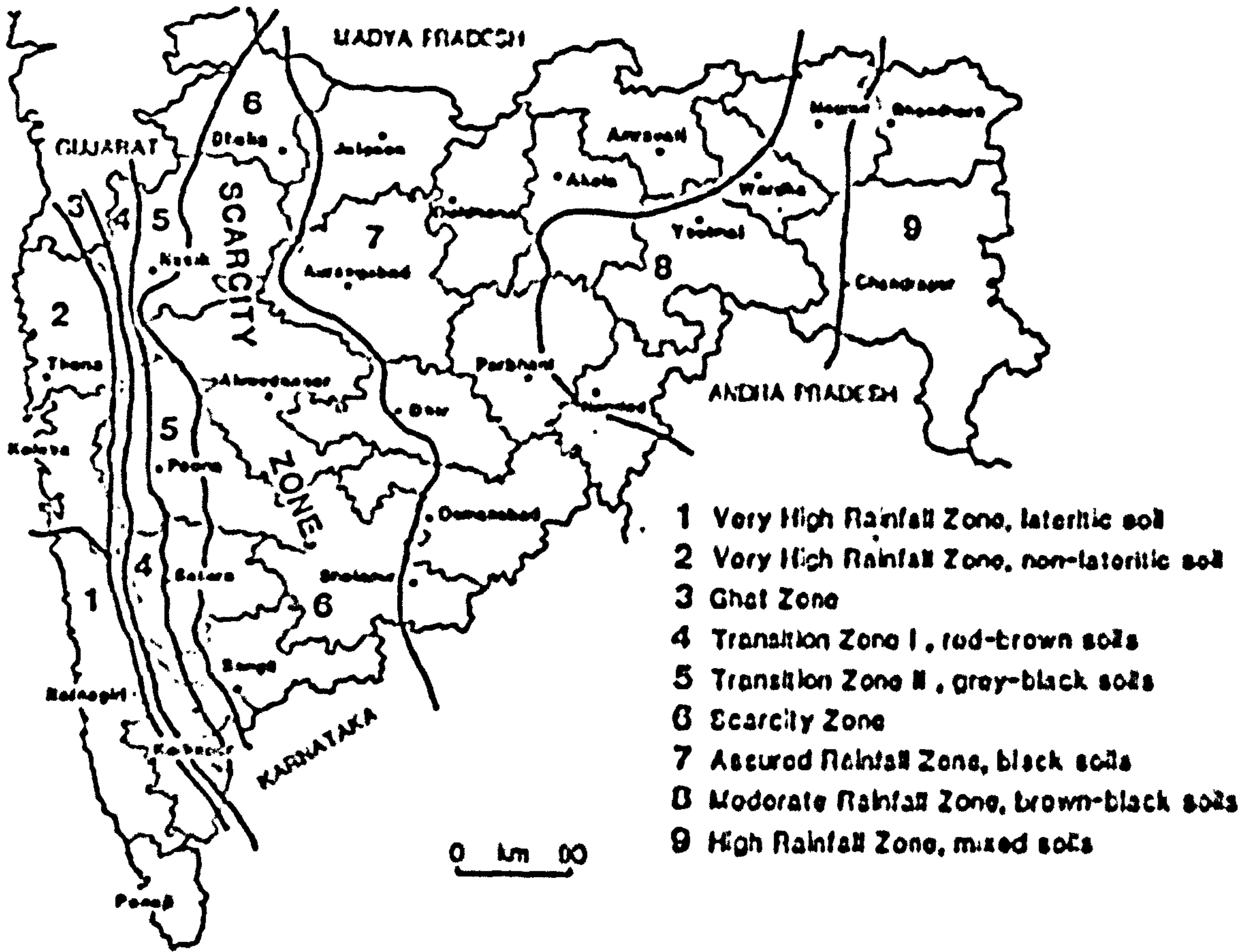
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APPENDIX 1
CROP CALENDAR AND AGROCLIMATIC ZONES OF
MAHARASHTRA

Growth periods of principal kharif crops



Crop calendar for the DPAM



Agroclimatic zones of Maharashtra

APPENDIX 2

DRY SPELL ANALYSIS

Analysis of dryspells has developed both to analysis simple frequencies of dryspells of time periods 1,2,3,...r, and the nature of persistence of dryness between one period and the subsequent period. The incidence of particular lengths of dryspell has often been of interest in planning, both in days in a dryspell that affect actual crop growth, but also time periods of dry years. Historical analysis to portray such risks helps in understanding of conditions of vulnerability and related policies of transformation. Analysis of persistence has been particularly important in weather forecasting and monitoring of drought conditions, and is important in understanding and designing coping strategies (for mitigation and damage restitution). In both cases there usually a close understanding developed of relations of dry conditions with the weather phenomena causing them, again helping with forecasting and choices of action.

For studying dryspells, or runs of dry periods,, it is useful to distinguish two sets of frequency information:-

i) frequencies of spells of exactly 1, 2, 3,... n days

$F_1, F_2, F_3 \dots F_n$

Let the sum of series $F_1 + F_2 + F_3 + \dots + F_n = Q$

While such a frequency study will show a general decline in frequencies, it will not be a smooth progression, and may show several minor peaks. This makes the sequence more difficult to model.

ii) frequencies of spells of at least 1, 2, 3 ... n days

$T_1, T_2, T_3 \dots T_n$, where

$T_1 = Q, T_2 = Q - F_1, T_3 = Q - (F_1 + F_2) \dots$

Let the sum of series $T_1 + T_2 + T_3 + \dots + T_n = S$

This frequency series is easier to analyse.

For understanding persistence, the statistical analysis of the frequency of runs of dry days is determined by assumptions on the nature of 'persistence' of dryness between one day and the subsequent day. One can identify three conditions of persistence:-

i) 'zero persistence' or 'constant probability', where the chances of a further day remain the same no matter how long the dry spell

ii) 'positive persistence', where the chance of a further dry spell increases as the length of dry spell increases

iii) 'negative persistence' or 'antipersistence', where the chance of a further dry day decreases as the length of dry spell increases.

While one pattern of persistence may prevail throughout the range of lengths of run, it is more likely that 'persistence' will vary as the length of run increases, as this is influenced by the life cycle of meteorological phenomena causing dry spells. Thus Belasco (1948), in a study of anticyclonic spells at Kew, found positive persistence in the range 3-20 day spells, but strong anti-persistence thereafter. Lawrence (1957) in a study of south England noted up to 5 persistence trends across longer dry spells, with positive persistence in spells 3-10 days, and in spells 20-25 days. He commented that a study of persistence over dry spells of varying lengths

gives a useful variable in differentiating 'weather areas', and in medium and long-range forecasting at a site.

Simple frequency studies

Data from (i) can be used to study average length of dryspell (l) from the formula

$$l_{\text{average}} = \frac{\sum l_n \cdot f_n}{\sum f_n} \quad \text{where } l \text{ is dryspell length and } f \text{ is frequency of spell of this length}$$

However, the higher incidence of small spells of days (1,2,3,4), often occurring several times in a month, hampers understanding of frequencies of longer dryspells, unless the study demarcates a minimum specific length for a dryspell and confines the study to frequencies of spells longer than this. Ratnam et al (1975) applied simple studies of this kind in Dharwar in India.

Alternatives using (ii) can be to

- i) from frequency data, assess the average number of times a dryspell event of at least ... r days occurs in a given month over a set of years. If a dryspell event S of at least ...t days occurs on average once in two years or 50% of the time, it could be labelled S_{50} .
- ii) rank to maximum dryspell event of at least ...t days occurring each year in a given month. This can related to recurrence interval (return period) and thence the probability of such a magnitude of a size of event occurring in that month in a given year.

The earliest studies of probabilities in the dry areas of India developed to study the probability of spells of at least r days (r days or more). These were estimated by calculating actual number of spells of at least r days in a given month over a set of years, as a percentage of the total number of spells in that month in the years under analysis (Ratnam et al, 1975). However, this is a complex calculation for longer spells that run over one month or across months.

Some workers (Buishand 1978) have fitted discrete probability distributions to dry spell frequencies. The most appropriate is the Negative Binomial Distribution (NBD) developed from the Binomial Distribution (see Haan 1977). In practice, however, there were very few advantages of distribution fitting over the use of series, the technique involving at least equal amounts of computation. Furthermore, the values generated by the NBD are similar to those generated by a logarithmic series. The NBD also made the assumption that p, the chance of a dry day, was constant throughout the dry spell. For these reasons, probability distributions are not fitted in this report.

Studies to assist weather study and forecasting

Dry spells form a series of discontinuous, independent events. A study of the frequencies of spells of 1, 2, 3 ... n days is thus suited to analysis by mathematical series.

Appropriate Mathematical Series

- i) *to generate frequencies of at least n days*, there have been two approaches

a) the geometric series

of the formN, NP^2 , NP^3 , ... NP^{n-1} provides the simplest solution.

There is great similarity between this and the binomial distribution.

N = number of spells of at least 1 day

P = constant probability that the dry spell will last at least one more day

P is easily solved, since the sum of this geometric progression, which is also the sum of frequency series S is

$$S = \frac{N}{1-P} \quad \text{i.e.} \quad P = 1 - \frac{N}{S}$$

Lawrence has shown that this simple series can give a reasonable forecast of frequencies, although a more appropriate value for P emerged if the study commenced from a 3-day dry spell i.e. N = frequency of spells of at least 3 days, NP = frequency of spells of at least 4 days etc.

The disadvantage of this series is use of a constant P value, which is unrealistic in most climatological conditions.

b) *the 'natural persistence series'*

In this series the frequency of runs lasting at least 2, 3 ... t days can be represented by

$$N, Np_2p_3, Np_2p_3p_4, \dots, Np_2p_3 \dots p_n$$

$$\text{where } p_n = \frac{\text{number of spells lasting at least } t \text{ days}}{\text{number of spells lasting at least } (t-1) \text{ days}}$$

where $n > 1$

N = number of spells lasting at least 1 day

$$P_1 = \frac{\text{number of dry days}}{\text{total number of days}}$$

This series, although it involves more computation, is still easy to generate, and has the advantage of providing a set of 'persistence possibilities' which vary as the spell grows longer. These can be used for spatial comparison and forecasting in the way suggested by Lawrence (1957). Lawrence also found that this series gave the best results in generating frequencies.

The persistence probability P_n that a dry day will persist as a dryspell for at least 2, 3, 4... n days can be represented by

$$P_2, P_2P_3, P_2P_3P_4, \dots, P_2P_3P_4 \dots P_n$$

The natural persistence series has been used to analyse dry spell frequencies and series in this study. It is considered that this series takes the most realistic attitude to persistence, and it is also an easy series to compute once the frequency study has been made.

ii) *to generate frequencies for spells of exactly 1 2 3 ... n days*

c) *The logarithmic series* has been most commonly applied. The components of a histogram of this frequency series could be represented by an equation of the form

$$a + ac_1x + ac_2x^2 + ac_3x^3 + \dots + ac_nx^{n-1}$$

where c and x combine to give a probability which can change over the period.

The logarithmic series

$$-(x + \frac{x^2}{2} + \frac{x^3}{3} + \dots + \frac{x^n}{n} \dots)$$

can be used as an approximation. This can be developed for dry spell series as

$$Q = a + \frac{ar}{2} + \frac{ar^2}{3} + \frac{ar^3}{4} + \dots + \frac{ar^{n-1}}{n} \quad (i)$$

The summation for $(x + \frac{x^2}{2} + \frac{x^3}{3} + \dots + \frac{x^n}{n} \dots)$ is $\log_e(1-x)$

Thus for a set of dry spell frequencies modelled by equation (i)

$$Q = -\frac{a}{r} \log_e(1-r)$$

The effect of the logarithmic series is to imply positive persistence, i.e. the longer the dry spell, the more likely that another day will be dry, but the persistence effect is still controlled. In equation (i) a and r are both site specific. (Lawrence (1957) proposed a graphical solution but it makes the series difficult to compute.

Where dry spells in a month are studied, one must consider spells which last over the end of the month. Two conventions have been used in the literature:

- i) Buishand (1977) allocated all spells commencing in month m to month m
- ii) Lawrence (1957) allocated a spell which ran over the month to the month which experienced the greater portion of the spell. If a spell was divided equally between months then half the spell was allocated to each month concerned.

The second convention has been used in this analysis as it is more appropriate to the pattern of monsoon rainfall. The first convention would reduce the illustration of the driest month, as, for example, longer spells covering much of August but starting at the end of July would be allocated to July.

After compilation of maps using the persistence probability criteria, the following give the best spatial distinction within the DPAM:-

- (i) for June, (P_{10}).
 - (ii) for July, also (P_{10}), also provided useful distinctions and provided more information than a map of (P_{15}). The map of the 50 per cent dry spell S_{50} also provided some interesting contrasts;
 - (iii) for August the map of (P_{15}) provided a very good spatial contrast, however, the maps of (P_{15}) and (S_{50}) distinguish core areas of long dry spells more clearly, and are given in Chapter 3;
 - (iv) for September, none of the criteria reflected very clear contrasts, perhaps because this month is often one of showers and dry spells across the entire state. (P_{15}) gave the clearest distinctions.
 - (v) in October (P_{15}) provided the greatest spatial information.
- More details of the analysis by month are given in Vincent (1978).

The following frequency tables show runs of at least N days, from analysis of rainfall records 1901-1976 for selected stations in the DPAM

Frequency of spells of at least n days, July

Station	5	10	15	20	25	30
Madison	94	79	8	4	0	0
Polk	76	22	8	1	1	1
Perkins	91	22	11	3	0	0
Madison	87	30	9	1	0	0
Smith	112	42	16	4	1	0
Madison	126	56	28	10	4	3
Madison	90	29	21	9	2	1
Madison	119	42	21	6	1	0
Madison	125	56	22	10	11	5
Madison	119	66	26	10	9	2
Madison	96	21	9	2	1	0
Madison	91	27	12	2	0	0
Madison	116	56	22	11	4	1
Madison	91	20	6	2	1	0
Madison	120	72	44	27	16	9
Madison	116	51	10	7	2	1
Madison	107	44	19	6	2	1
Madison	117	60	28	15	9	2
Madison	43	12	6	2	2	1
Madison	94	26	8	3	0	0
Madison	97	15	4	2	0	0
Madison	12	10	1	0	0	0

Frequency of spells of at least n days, August

Station	5	10	15	20	25	30
Madison	116	24	16	5	2	2
Polk	90	20	17	6	1	1
Perkins	100	21	11	4	2	1
Madison	90	25	7	1	1	1
Smith	122	57	26	16	4	2
Madison	120	91	40	20	10	7
Madison	111	48	25	7	4	1
Madison	116	51	29	11	6	1
Madison	111	75	54	24	10	11
Madison	116	64	51	22	12	9
Madison	90	26	11	4	1	0
Madison	118	54	26	16	4	2
Madison	120	47	27	22	22	15
Madison	117	42	11	6	1	0
Madison	120	75	54	24	24	16
Madison	119	60	24	16	10	5
Madison	116	44	31	10	11	9
Madison	117	71	40	24	10	11
Madison	94	20	9	4	2	1
Madison	117	40	24	9	4	0
Madison	94	22	8	2	2	2
Madison	71	21	6	2	1	1

Frequencies of dry spells of at least 5 days, October

Station	5	10	15	20	25	30
Mohlar	84	65	54	35	36	
Jalgaon	73	64	57	32	42	37
Padra	73	63	54	32	44	43
Mahabub	75	62	54	31	43	28
Dholi	76	93	92	42	34	31
Mulgaon	89	71	48	41	26	30
Aurangabad	85	62	47	39	31	25
Waghod	85	46	47	26	28	23
Surat	89	60	41	23	25	19
Ahmednagar	90	39	47	32	17	17
Amravati	89	38	47	24	19	14
Pune	203	44	39	22	11	9
Karnala	98	43	43	35	23	19
Osmanabad	90	60	41	22	21	16
Mahitra	201	40	26	23	17	12
Mulgaon	102	38	43	29	17	14
Vite	65	58	37	22	17	11
Jeth	98	53	35	20	14	8
Shirala	111	60	33	19	8	6
Abela	77	44	31	42	34	20
Surat	79	57	31	42	34	28
Chandrapur	82	60	48	39	29	22

Frequencies of dry spells of at least 10 days, September

Station	5	10	15	20	25	30
Mohlar	86	44	29	7	3	3
Jalgaon	94	48	37	11	7	6
Padra	85	26	14	6	5	1
Mahabub	111	51	26	11	6	6
Dholi	104	52	27	7	6	4
Mulgaon	106	43	18	10	4	2
Aurangabad	111	46	22	11	3	4
Waghod	112	33	24	10	8	2
Surat	108	62	21	13	7	3
Amravati	114	30	18	11	6	3
Amravati	113	29	33	15	7	2
Pune	116	49	25	14	8	3
Karnala	114	52	26	14	7	3
Osmanabad	93	28	12	4	1	1
Mahitra	121	30	24	12	4	2
Sholapur	113	43	37	13	2	1
Vite	117	34	24	15	8	4
Jeth	116	46	29	11	5	1
Shirala	125	63	31	14	5	2
Abela	113	55	24	6	2	1
Surat	93	26	14	7	5	2
Chandrapur	109	75	7	3	1	6

APPENDIX 3

MOISTURE AVAILABILITY INDICES: THE STUDY OF RUNS OF YEARS WITH DEPRESSED YIELDS

A computer programme was designed to print out the ratio of actual monthly rainfall to average monthly PET for all months 1901-1976. Humid and moist months (ratio >0.5) were distinguished from moderately dry and dry months (ratio <0.5). A number of criteria were then developed to monitor different kinds of kharif and rabi risks, and thus to establish the overall level of drought risks and spells of drought years.

The specific meteorological events which result in crop failure are:-

- (i) late onset of the monsoon rains (after mid July) or complete failure of the monsoons. The criteria to test for this were (a) no humid or moist month before August, and (b) no humid or moist month until September.
- (ii) Low rainfall or dry spells after onset. The criteria to test for these was a moderately dry or dry month (or months) after a moist or humid month marking onset. This criteria also enables a study of the changes of 1,2,3... months of good rainfall for kharif production.
- (iii) Moderately dry or dry September. This could indicate delayed planting of rabi crops, although this is not an automatic source of low crop yields.
- (iv) Inadequate rainfall for rabi crops. Rabi risks must be considered in relation to soil depth and moisture storage. Section 2.3 suggested that deep soils over 90cm can support a rabi crop without further showers, after good rains in September. Medium soils in the range 50-90cm., however, need further showers in October/November to support a reasonable crop. Thus two criteria were established:
 - (a) no moist or humid month in either September or October. This leads to crop failure on all rabi soils, deep and medium.
 - (b) Only one moist or humid month in September or October. This will seriously depress yields from rabi crops on all but very deep soils.

Criteria (i) and (ii) combine to give 'kharif risks', criteria (iv) gives 'rabi risks' and from these the sequences of years of poor kharif and rabi crops can be established.

Chapter three has pointed out, however, that it is not enough to consider the frequency of bad years, one must consider the incidence of very good years which would generate surplus for investment, as well as sequences of bad years. Thus one can also distinguish:

- (v) Years of 3,4,5 consecutive humid or moist months after onset, to provide good kharif crops.

- (i) in kharif, 'total failure' will result from either failure of onset, late onset of the monsoon in August or if there are two or more dry or moderately dry months in succession. General depressed yields will result if there is one dry or moderately dry month
- (ii) in rabi, 'total rabi failure' will result if there is no moisture or humid month in September or October. 'General depressed yields' are likely if only one moist or humid month is received, especially on the medium deep soils. The risks from a dry September, because they depend on other features such as temperature, are not included in the study.

APPENDIX 4

GEOLOGY AND WELL DEVELOPMENT IN RAYALASEEMA

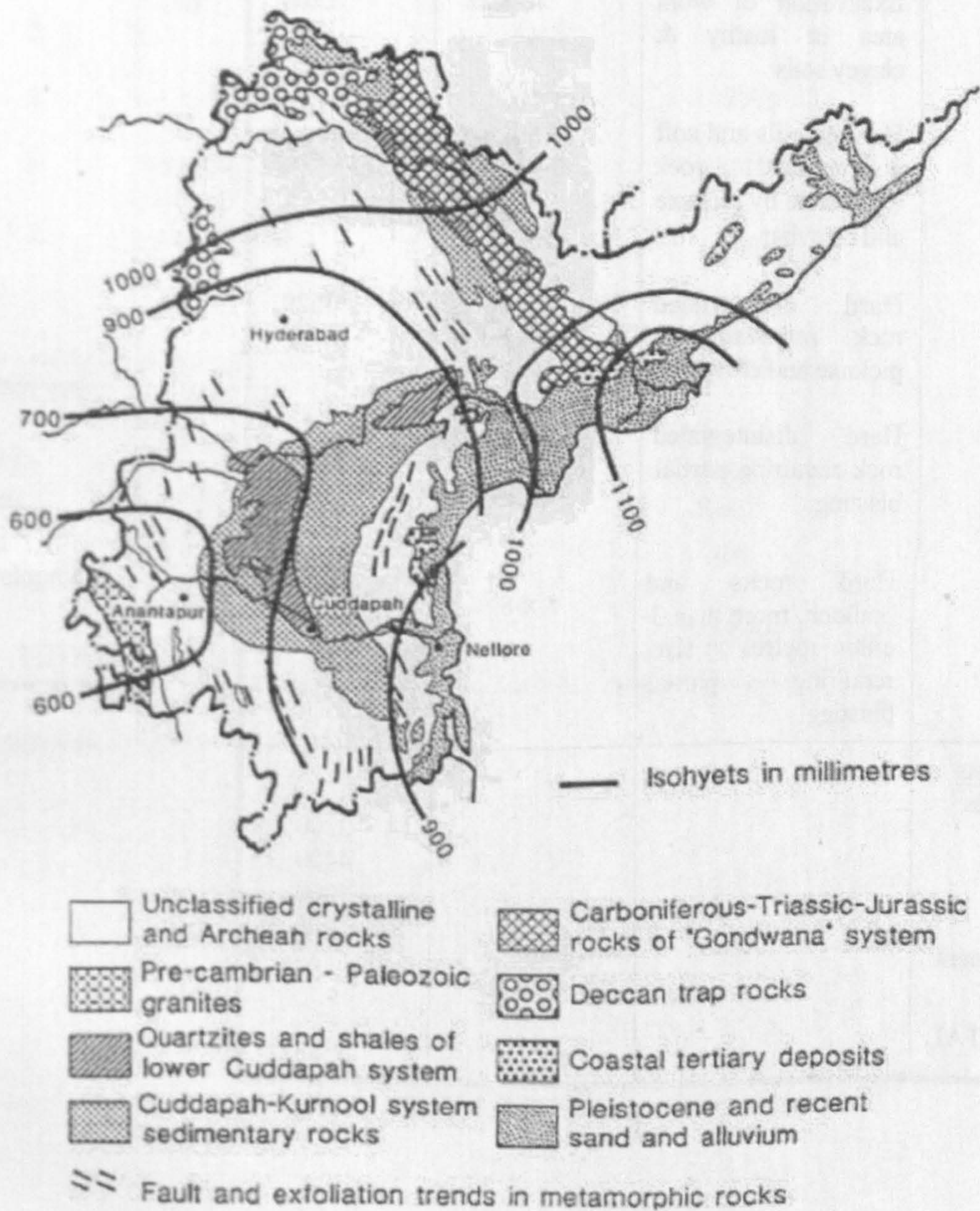


Fig. A4 .1 Annual rainfall and geology of Andhra Pradesh

Table A 4.1 Standard costs in well requiring blasting

Depth	Description	Length & width (m)	Cost (rs)
2	Excavation of work area in loamy & clayey soils	22 x 22	2205
2	Hard gravels and soft disintegrated rock removable by pickaxe and crowbar	8 x 8	463
2			
2	Hard disintegrated rock removable by pickaxe and crowbar	8 x 8	1529
	Hard disintegrated rock requiring partial blasting	8 x 8	3978
	Hard rocks and boulders more than 3 cubic metres in size requiring partial blasting	8 x 8	14277
			23152
Other costs ¹			
explosives			2200
lining			4400
pump			5000
land development			500
TOTAL			35252

Table A.4.2 Standard costs in well not requiring blasting, 1983/84

Depth	Description	Length & width (m)	Cost (rs)
2	Excavation of work area in loamy & stiff clay	22 x 22	2905
2		8 x 8	553
2	<i>Mattus</i> 1-4	8 x 8	1105
2	All in soft disintegrated rock removable by pickaxe and crowbar	8 x 8	2210
2		8 x 9	3715
			10038
<u>Other costs¹</u>			
lining			8000
pump			5000
land development			500
TOTAL			22932

One mattu is 2 metres

Table A4.3 Excavation cost of CI well at Cherlokothur, Dhone block, Kurnool district (1983/84 costs)

Mattu (2m)	Description	Length & width (m)	Cost (rs)
1	Loamy & stiff clay	10 x 10	518
2	Gravel & soft disintegrated rock	10 x 10	1057
3	Soft disintegrated rock removable by pickaxe and crowbar	10 x 10	2047
4)) 5))	Hard disintegrated rock removable by pickaxe and crowbar	10 x 10	<u>4655</u>
			11381
<u>Other costs</u> ¹ Dry stone masonry, including cost, conveyance and labour (top 2½ mattu only)			2530
baling out charges			<u>2155</u>
TOTAL			16066

1. carries comment "baling and lining adjusted to keep within total" (150000 R).

Source: Panchayat Samiti records, Dhone Block, Kurnool District.

Table A4.4. Actual excavation cost of CI well at Venkataraymipalli, Dhone block, Kurnool district (1983/84 prices)

Mattu	Description	Length & Width (m)	Cost (Rs)
1	Loamy & stiff clay	10 x 10	519
2	Soft disintegrated rock removed by pickaxe and crowbar	10 x 10	1410
3	Hard disintegrated rock removed by pickaxe and crowbar	7.5 x 7.5	2217
4	Hard disintegrated rock requiring partial blasting	7.5 x 7.5	4035
			8181
<u>Other costs</u>			
Dry stone masonry, including cost, conveyance and labour (all <i>mattus</i> claimed)			3725
Baling charge, 30 days at 70R per day			<u>2100</u>
Subtotal			14006
P.S. charges			<u>994</u>
TOTAL			15000

Source: DRDA Records, Kurnool.

Table A4.5. Actual excavation cost of well at M.Thimmapuram, Nandyal block, Kurnool district (1983/84 prices)

Mattu	Description	Length & width (m)	Cost
1	Black cotton soils & hard gravelly soils		401
2	Hard soils & soft disintegrated rock		871
3)	Hard rock soils requiring partial blasting		2392
)			<u>4227</u>
4)			8236
<u>Other costs</u> Baling out charges Blasting materials			2302 <u>1354</u> 11892

No details of lining.

Source: DRDA Records, Kurnool.